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Annual Report of the Board of Regents

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SMITHSONIAN
INSTITUTION



PUBLICATION 4435

Showing the Operations, Expenditures, and Condition of the

Institution for the Year Ended June 30

1960

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LETTER OF TRANSMITTAL

SMITHSONIAN INSTITUTION,
Washington, December 27, 1960.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, on behalf of the Board of Regents, to submit to Congress the annual report of the operations, expenditures, and condition of the Smithsonian Institution for the year ended June 30, 1960.

Respectfully,

LEONARD CARMICHAEL, *Secretary.*

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THE SMITHSONIAN INSTITUTION

June 30, 1960

Presiding Officer ex officio.—DWIGHT D. EISENHOWER, President of the United States.

Chancellor.—EARL WARREN, Chief Justice of the United States.

Members of the Institution:

DWIGHT D. EISENHOWER, President of the United States.

RICHARD M. NIXON, Vice President of the United States.

EARL WARREN, Chief Justice of the United States.

CHRISTIAN A. HERTER, Secretary of State.

ROBERT B. ANDERSON, Secretary of the Treasury.

THOMAS S. GATES, JR., Secretary of Defense.

WILLIAM P. ROGERS, Attorney General.

ARTHUR E. SUMMERFIELD, Postmaster General.

FRED A. SEATON, Secretary of the Interior.

EZRA TAFT BENSON, Secretary of Agriculture.

FREDERICK H. MUELLER, Secretary of Commerce.

JAMES P. MITCHELL, Secretary of Labor.

ARTHUR S. FLEMMING, Secretary of Health, Education, and Welfare.

Regents of the Institution:

EARL WARREN, Chief Justice of the United States, Chancellor.

RICHARD M. NIXON, Vice President of the United States.

CLINTON P. ANDERSON, Member of the Senate.

J. WILLIAM FULBRIGHT, Member of the Senate.

LEVERETT SALTONSTALL, Member of the Senate.

FRANK T. BOW, Member of the House of Representatives.

OVERTON BROOKS, Member of the House of Representatives.

CLARENCE CANNON, Member of the House of Representatives.

JOHN NICHOLAS BROWN, citizen of Rhode Island.

ARTHUR H. COMPTON, citizen of Missouri.

ROBERT V. FLEMING, citizen of Washington, D.C.

CRAWFORD H. GREENEWALT, citizen of Delaware.

CARYL P. HASKINS, citizen of Washington, D.C.

JEROME C. HUNSAKER, citizen of Massachusetts.

Executive Committee.—ROBERT V. FLEMING, *chairman*, CLARENCE CANNON, CARYL P. HASKINS.

Secretary.—LEONARD CARMICHAEL.

Assistant Secretaries.—J. L. KEDDY, A. REMINGTON KELLOGG.

Assistant to the Secretary.—JAMES C. BRADLEY.

Administrative assistant to the Secretary.—MRS. LOUISE M. PEARSON.

Treasurer.—EDGAR L. ROY.

Chief, editorial and publications division.—PAUL H. OEHSE.

Librarian.—RUTH E. BLANCHARD.

Curator, Smithsonian Museum Service.—G. CARROLL LINDSAY.

Buildings Manager.—ANDREW F. MICHAELS, JR.

Director of Personnel.—L. C. WESTFALL.

Chief, supply division.—A. W. WILDING.

Chief, photographic service division.—O. H. GREENSON.

UNITED STATES NATIONAL MUSEUM

Director.—A. Remington Kellogg.

Registrar.—Helena M. Weiss.

MUSEUM OF NATURAL HISTORY

Director.—A. C. Smith.

DEPARTMENT OF ANTHROPOLOGY: F. M. Setzler, head curator; A. J. Andrews, exhibits specialist.

Division of Archeology: W. R. Wedel, curator; Clifford Evans, Jr., G. W. Van Beek, associate curators.

Division of Ethnology: S. H. Riesenbergs, curator; G. D. Gibson, E. I. Knez, associate curators; R. A. Elder, Jr., assistant curator.

Division of Physical Anthropology: T. D. Stewart, curator; M. T. Newman, associate curator.

DEPARTMENT OF ZOOLOGY: Herbert Friedmann, head curator.

Division of Mammals: D. H. Johnson, curator; C. O. Handley, Jr., H. W. Setzer, associate curators.

Division of Birds: Herbert Friedmann, acting curator; H. G. Deignan, associate curator.

Division of Reptiles and Amphibians: Doris M. Cochran, curator.

Division of Fishes: L. P. Schultz, curator; E. A. Lachner, W. R. Taylor, associate curators.

Division of Insects: J. F. G. Clarke, curator; O. L. Cartwright, R. E. Crabill, Jr., W. D. Field, associate curators; Sophy Parfın, assistant curator.

Division of Marine Invertebrates: F. A. Chace, Jr., curator; F. M. Bayer, T. E. Bowman, C. E. Cutress, Jr., associate curators.

Division of Mollusks: H. A. Rehder, curator; J. P. E. Morrison, associate curator.

DEPARTMENT OF BOTANY (NATIONAL HERBARIUM): J. R. Swallen, head curator.

Division of Phanerogams: L. B. Smith, curator; R. S. Cowan, E. C. Leonard, Velve E. Rudd, J. J. Wurdack, associate curators.

Division of Ferns: C. V. Morton, curator.

Division of Grasses: J. R. Swallen, acting curator.

Division of Cryptogams: M. E. Hale, Jr., acting curator; P. S. Conger, associate curator; R. R. Ireland, Jr., assistant curator.

Division of Woods: W. L. Stern, curator.

DEPARTMENT OF GEOLOGY: G. A. Cooper, head curator.

Division of Mineralogy and Petrology: G. S. Switzer, curator; R. S. Clarke, Jr., P. E. Desautels, E. P. Henderson, associate curators.

Division of Invertebrate Paleontology and Paleobotany: G. A. Cooper, acting curator; R. S. Boardman, P. M. Kier, Richard Cifelli, associate curators; E. G. Kauffman, assistant curator.

Division of Vertebrate Paleontology: C. L. Gazin, curator; D. H. Dunkle, Nicholas Hotton, III, associate curators; F. L. Pearce, exhibits specialist.

MUSEUM OF HISTORY AND TECHNOLOGY

Director.—F. A. Taylor.

Assistant Director.—J. C. Ewers.

Chief exhibits specialist.—J. E. Anglim.

Chief zoological exhibits specialist.—(Vacant.)

Assistant chief exhibits specialists.—B. S. Bory, R. O. Hower, B. W. Lawless, Jr.

DEPARTMENT OF SCIENCE AND TECHNOLOGY: R. P. Multhauf, head curator.

Division of Physical Sciences: R. P. Multhauf, acting curator.

Division of Mechanical and Civil Engineering: E. S. Ferguson, curator; E. A. Battison, associate curator; R. M. Vogel, assistant curator.

Division of Transportation: H. I. Chapelle, curator; K. M. Perry, associate curator; J. H. White, Jr., assistant curator.

Division of Electricity: W. J. King, Jr., acting curator.

Division of Medical Sciences: J. B. Blake, curator, S. K. Hamarneh, associate curator.

DEPARTMENT OF ARTS AND MANUFACTURES: P. W. Bishop, head curator.

Division of Textiles: Grace L. Rogers, acting curator.

Division of Ceramics and Glass: P. V. Gardner, acting curator.

Division of Graphic Arts: Jacob Kainen, curator; F. O. Griffith, 3d, assistant curator.

Division of Agriculture and Forest Products: E. C. Kendall, acting curator.

Division of Industrial Cooperation: P. W. Bishop, acting curator; Charles O. Houston, Jr., associate curator.

DEPARTMENT OF CIVIL HISTORY: A. N. B. Garvan, head curator; P. C. Welsh, associate curator.

Division of Political History: W. E. Washburn, curator, Mrs. Margaret B. Klapthor, associate curator; C. G. Dorman, Mrs. Anne W. Murray, assistant curators.

Division of Cultural History: C. M. Watkins, acting curator; J. D. Shortridge, Rodris C. Roth, associate curators; John N. Pearce, assistant curator.

Division of Philately and Postal History: G. T. Turner, acting curator; F. J. McCall, associate curator; C. H. Scheele, assistant curator.

Division of Numismatics: Vladimir Clain-Stefanelli, acting curator; Mrs. Elvira Clain-Stefanelli, assistant curator.

DEPARTMENT OF ARMED FORCES HISTORY: M. L. Peterson, head curator.

Division of Military History: E. M. Howell, acting curator; C. R. Goins, Jr., assistant curator.

Division of Naval History: M. L. Peterson, acting curator; P. K. Lundeberg, associate curator.

BUREAU OF AMERICAN ETHNOLOGY

Director.—F. H. H. Roberts, Jr.

Anthropologist.—H. B. Collins, Jr.

Ethnologists.—W. C. Sturtevant, W. L. Chafe.

RIVER BASIN SURVEYS.—F. H. H. Roberts, Jr., *Director*; R. L. Stephenson, *Chief, Missouri Basin Project*.

ASTROPHYSICAL OBSERVATORY

Director.—F. L. Whipple.

Associate Director.—J. A. Hynek.

Astrophysicists.—R. J. Davis, E. L. Fireman, L. G. Jacchia, Max Krook, F. B. Riggs, Jr., C. A. Whitney.

Mathematician.—R. E. Briggs.

TABLE MOUNTAIN, CALIF., FIELD STATION.—A. G. Frolland, *physicist*.

DIVISION OF RADIATION AND ORGANISMS:

Chief.—W. H. Klein.

Plant physiologists.—V. B. Elstad, Leonard Price, E. C. Sisler.

Electronic engineer.—J. H. Harrison.

Instrument maker.—D. G. Talbert.

NATIONAL COLLECTION OF FINE ARTS

Director.—T. M. Beggs.

Associate curator.—Rowland Lyon.

SMITHSONIAN TRAVELING EXHIBITION SERVICE.—Mrs. Annemarie H. Pope, *Chief*.

FREER GALLERY OF ART

Director.—A. G. Wenley.

Assistant Director.—J. A. Pope.

Associate in Near Eastern art.—Richard Ettinghausen.

Curator, Laboratory.—R. J. Gettens.

Associate curators.—J. F. Cahill, H. P. Stern.

NATIONAL AIR MUSEUM

Advisory Board:

Leonard Carmichael, *Chairman*.

Maj. Gen. Brooke C. Allen, U.S. Air Force.

Rear Adm. P. D. Stroop, U.S. Navy.

Lt. Gen. James H. Doolittle.

Grover Loening.

Director.—P. S. Hopkins.

Head curator and historian.—P. E. Garber.

Associate curators.—L. S. Casey, W. M. Male, K. E. Newland.

Junior curator.—R. B. Meyer.

NATIONAL ZOOLOGICAL PARK

Director.—T. H. Reed.

Associate Director.—J. L. Grimmer.

Veterinarian.—James F. Wright.

CANAL ZONE BIOLOGICAL AREA

Resident Naturalist.—M. H. Moynihan.

INTERNATIONAL EXCHANGE SERVICE

Chief.—J. A. Collins.

NATIONAL GALLERY OF ART

Trustees:

EARL WARREN, Chief Justice of the United States, *Chairman*.

CHRISTIAN A. HERTER, Secretary of State.

ROBERT B. ANDERSON, Secretary of the Treasury.

LEONARD CARMICHAEL, Secretary of the Smithsonian Institution.

F. LAMMOT BELIN.

DUNCAN PHILLIPS.

CHESTER DALE.

PAUL MELLON.

RUSH H. KEES.

President.—CHESTER DALE.

Vice President.—F. LAMONT BELIN.

Secretary-Treasurer.—HUNTINGTON CAIENS.

Director.—JOHN WALKER.

Administrator.—ERNEST R. FEIDLER.

General Counsel.—HUNTINGTON CAIENS.

Chief Curator.—PERRY B. COTT.

Honorary Research Associates, Collaborators, and Fellows

OFFICE OF THE SECRETARY

John E. Graf

UNITED STATES NATIONAL MUSEUM

MUSEUM OF NATURAL HISTORY

Anthropology

Mrs. Arthur M. Greenwood.
N. M. Judd, Archeology.
H. W. Krieger, Ethnology.
Betty J. Meggers, Archeology.

H. Morgan Smith, Archeology.
W. W. Taylor, Jr., Archeology.
W. J. Tobin, Physical Anthropology.

Zoology

J. Bruce Bredin.
M. A. Carriker, Insects.
C. J. Drake, Insects.
Isaac Ginsberg, Fishes.
D. C. Graham, Biology.
Horton H. Hobbs, Jr., Marine
Invertebrates.
A. B. Howell, Mammals.
Laurence Irving, Birds.
W. L. Jellison, Insects.
W. M. Mann, Hymenoptera.

Allen McIntosh, Mollusks.
J. P. Moore, Marine Invertebrates.
C. F. W. Muesebeck, Insects.
W. L. Schmitt.
Benjamin Schwartz, Helminthology.
R. E. Snodgrass, Insects.
T. E. Snyder, Insects.
Alexander Wetmore, Birds.
Mrs. Mildred S. Wilson, Copepod
Crustacea.

Botany

Mrs. Agnes Chase, Grasses.
E. P. Killip, Phanerogams.

F. A. McClure, Grasses.
J. A. Stevenson, Fungi.

Geology

R. S. Bassler, Paleontology.
C. Wythe Cooke, Invertebrate
Paleontology.

W. T. Schaller, Mineralogy.

MUSEUM OF HISTORY AND TECHNOLOGY

Exhibits

William L. Brown.

History

Elmer C. Herber.
Ivor M. Hume.

F. W. MacKay, Numismatics.

Science and Technology

Derek J. Price.

BUREAU OF AMERICAN ETHNOLOGY

J. P. Harrington.
Sister M. Inez Hilger.

M. W. Stirling.
A. J. Waring, Jr.

ASTROPHYSICAL OBSERVATORY

C. G. Abbot.

FREER GALLERY OF ART

Oleg Grabar.

Grace Dunham Guest.

| Max Loehr.

| Katherine N. Rhoades.

NATIONAL AIR MUSEUM

Frederick C. Crawford.

| John J. Ide.

NATIONAL ZOOLOGICAL PARK

W. M. Mann.

| E. P. Walker.

CANAL ZONE BIOLOGICAL AREA

C. C. Soper.

Report of the Secretary of the Smithsonian Institution

LEONARD CARMICHAEL

For the Year Ended June 30, 1960

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: I have the honor to submit a report showing the activities and condition of the Smithsonian Institution and its branches for the fiscal year ended June 30, 1960.

GENERAL STATEMENT

It is perennially amazing, in rereading the history of the Smithsonian Institution, to realize the wisdom that guided the founder, James Smithson, and the prime organizer and first Secretary, Joseph Henry. Smithson directed, in his now famous phrase, that his institution concern itself with "the increase and diffusion of knowledge among men." This was indeed a broad and humane prescription. Equally so was Joseph Henry's interpretation of it when he came to lay down the fundamental plan of the Institution. Said Henry: "Smithson's will makes no restriction in favor of any particular kind of knowledge, and hence all branches are entitled to a share of attention. He was well aware that knowledge should not be viewed as existing in isolated parts, but as a whole, each portion of which throws light on all the others, and that the tendency of all is to improve the human mind, and to give it new sources of power and enjoyment." He further added, "To effect the greatest good, the organization of the Institution should be such as to produce results which could not be attained by other means."

The social import of the Smithsonian's broad and inspiring charter has never been more obvious than it is in today's atomic age when the great modern achievements in science and technology, which daily impress themselves upon every citizen, call for the widest and most liberal basis of understanding. But this is still an age in which enlightenment is far from universal. A great responsibility, therefore, rests upon those individuals and institutions into whose hands has been placed the preservation of our cultural and scientific heritage

to provide, in every effectual way, those new sources of intellectual power that Joseph Henry visualized so that every citizen will aspire to an understanding of this complex modern world and feel himself a part of man's upward struggle.

We have an obligation to the future. In shaping our museum halls, we must render human history—of our environment, our ideas, or technical achievements, our institutions, our manners and customs, our daily lives—meaningful to the citizens of tomorrow as well as of today. It is, also, our responsibility to raise the general level of cultural appreciation, to educate in the broadest sense, and to encourage people to seek knowledge of the highest order. The Smithsonian Institution has an important role to fulfill in meeting these responsibilities. Through its great museums, art galleries, research laboratories, and explorations, it seeks not only to preserve and document the full range of our history but also to interpret it to the public.

Scientific and other scholarly research, educational exhibits, publication of new advances in knowledge, facilitation of worldwide interchange of published scientific and literary information, and, within the Institution's resources, the fostering and stimulation of scholarly endeavor—all are part of the work of today's Smithsonian, just as they have been during all the 114 years since its establishment. A great museum must be more than a laboratory or a showcase. It must be a center of interpretation and inspiration for its millions of visitors.

In these first paragraphs of this year's Smithsonian Report, it seems especially appropriate, therefore, to give particular attention to the growing significance of the Institution's museum exhibits. We are in the midst of extensive building and modernization programs which have already had their impact upon the visiting public; and it may be salutary to analyze some of the factors involved.

Both in April and again in May of this year more than a million people, by actual count, came to the old buildings of the Smithsonian. This does not include those who, during this time, visited the National Gallery of Art and the National Zoological Park. Never before in a single month have so many visitors come to the Smithsonian, or probably to any other museum complex in the world. In fact, as recently as 1953 the largest total monthly attendance was almost exactly one-half the figure for this year's banner months.

What has caused this explosive increase? There seems to be no doubt that this amazing growth in public interest in the Smithsonian is due to the many new, vital, and effective renovated museum halls which have been opened to the public during the past few years. These new halls include the First Ladies Hall, the American Indian Hall,

the North American Mammals Hall, the Latin American Archeology Hall, the Bird Hall, the American Cultural History Hall, the Power Machinery Hall, the Second American Indian Hall, the Hall of Health, the Military History Hall, the Printing Arts Hall, the Gems and Minerals Halls, the Textile Hall, the Jade Room, the World of Mammals Hall, and the Agricultural Hall. Each of these revitalized exhibit areas is really a museum in itself. Each one alone has great visitor-attraction potential purely from an educational standpoint. Furthermore, in each of the modernized halls, the Smithsonian has been guided by new general museum principles and has used a variety of means to achieve the objectives mentioned above which the curators and designers had in mind in planning and constructing the halls.

The basic new philosophy of the nature of the museum that is illustrated in each rejuvenated hall is that exhibits should be so presented that the serious visitor may be both interested and instructed. In each new hall a visitor may, of course, be casually entertained, but he also is exposed to accurate, well-organized, attractively arranged segments of vital human knowledge. Thus, if he spends a moderate amount of time and effort in studying the sequences of objects and carefully reads the labels, he will be amply rewarded by a deeper and wider understanding of the complex world in which he lives. Aided by the modern exhibit techniques now available, the story of man and his world unfolds before the visitor as he walks from hall to hall. These new exhibits are in marked contrast to the static displays of yesterday. In the old days the viewer may have been impressed by the abundance of material exhibited but, for the most part, was neither instructed nor motivated to future study.

The Gems and Minerals Hall may be taken as an example of the effect of this new philosophy in dealing with a specific subject-matter field. The mineral collections of the Smithsonian, said to be the best of their kind in the world, have been built up during more than a century by gifts from interested friends all over the globe and by transfer to the Institution of outstanding specimens from the United States Geological Survey and other Federal bureaus. These collections are so extensive and important that many geological scientists come from every part of the country each year to work in our laboratories on special problems that can be solved only by the study of this material.

The public exhibits in the new Gems and Minerals Hall, however, represent only selected specimens from the total mineral collections of the Smithsonian. The problem, therefore, was first to select

for exhibition the best and most significant items from this array of material and then to tell the fascinating and often romantic story of minerals and gems systematically and in such a way as to be interesting and meaningful both to the casual visitor and to the individual who already knows much about scientific geology. The millions of visitors who have already studied this new hall since it was opened to the public two years ago have seen, under almost ideal conditions of museum light, the outstanding specimens of the world's principal minerals. The chemical structure of each of the great mineral classes and the specific make-up of each specimen are shown. The physics of crystals, as well as many interesting facts about the geographical distribution of minerals in the world's crust, is explained in labels and diagrams. Outstandingly valuable and beautiful gems are shown as examples of specific mineral groups. These displays, taken as a whole, are at once scientifically instructive and esthetically pleasing.

This new hall, which an unthinking person might in advance picture as a mere collection of rocks, has thus become so attractive that on busy days it is sometimes even necessary for the visitors to form in lines and move quickly past some of the more popular exhibits.

All this is in sharp contrast to the old days, when only the student who already had a real knowledge of mineralogy had the patience and the interest to stay in the old exhibit rooms and study in detail what the crowded cases contained. The nongeologist who came to the old mineral hall could hardly be expected to carry away with him any new understanding of geology as one of the great and humanly important sciences. For the novice there was no "plot" in the old form of exhibition, and its relation to his general knowledge was not indicated. It is no wonder that this "visual storage" type of exhibit often left little lasting impression. Today all this has changed. The static and repetitious tall, dark, wooden-framed cases are gone, and the science of mineral identification has been given a new meaning.

The transformation that has taken place in this single mineral hall may be cited as illustrating the general change that has been brought about in the older Smithsonian buildings as the present program of modernization of exhibits, in all the new halls enumerated above, has progressed.

It is not accidental, therefore, that the number of visitors to the Smithsonian Institution has doubled in the past few years. What the Smithsonian now presents to its visitors has new attractiveness and new educational significance. In every museum the person who enters its doors profits by his prior preparation for understanding and by the ease with which he can see the objects that are on display. In the

new Smithsonian exhibits, every effort is made to make each presentation logically clear and interesting so that the visitor will stop and read the explanatory labels. In this way, the Smithsonian exhibits improve the visitors' basic understanding of the natural history of America and of the world, of the history of many of the most important human arts and sciences, and of the technology that has made the modern world what it is. No one, for example, can go through the new American Cultural History Hall without seeing in a new way how Americans lived on this continent before the industrial revolution and how the coming of power machines transformed the basic ways of life of the Nation.

Thus the question as to what visitors gain by coming to the Smithsonian can be answered briefly: They gain in an understanding of the world in which they live and in their knowledge of America. Patriotism is a word that is sometimes misused, but who can doubt that any American citizen becomes more truly patriotic when he has knowledge of the basic natural resources of his country and of how these resources have been and are now used in the growth and maintenance of our modern life?

The increase in the number of visitors who come to the Smithsonian also indirectly reflects most favorably upon the basic attitudes of the citizens of our Nation today. It is inspiring to watch them passing in great streams through the doorways of our buildings. They come in order to see important exhibits, which they know in sum total can be viewed nowhere else in the world. Most of them surely leave with an understanding, which they could gain in no other way, of factors that have made modern life.

Some of the new exhibit halls that are now open in the Smithsonian's old Arts and Industries Building have been so constructed, by the use of portable panels, that when the new Museum of History and Technology is completed the whole display can be moved to the new building without unnecessary delay. When this is done, other exhibits of larger dimensions not at present on display will take their place in the old building. The professional staff is now working with exhibits experts in the preparation of other new halls so that there will be as little delay as possible in making the great new building an effective museum for the public as soon as its structure is complete.

Later pages of this report describe in detail the work done during the year by the staff of the Bureau of American Ethnology, the Smithsonian Astrophysical Observatory, the Freer Gallery of Art, the National Collection of Fine Arts, the National Air Museum, the Canal Zone Biological Area, the International Exchange Service, the National Zoological Park, and other specialized units of the Smithsonian.

May the opportunity be taken here to express, on behalf of everyone connected with the Smithsonian Institution, gratitude to the Congress of the United States for making available funds for the addition of a much-needed east wing to the Natural History Building and also for the air-conditioning and renovation of this old and important building. For more than a quarter of a century, published records show that Congress has recognized that the facilities of the Natural History Building are overcrowded and inadequate for the important scientific and museum functions assigned to it. It is a source of special rejoicing, therefore, that the Institution is now being allowed to develop facilities so that it will be able to accomplish far better scientific work in this building than was feasible in the past.

THE ESTABLISHMENT

The Smithsonian Institution was created by act of Congress in 1846, in accordance with the terms of the will of James Smithson, of England, who in 1826 bequeathed his property to the United States of America "to found at Washington, under the name of the Smithsonian Institution, an establishment for the increase and diffusion of knowledge among men." In receiving the property and accepting the trust, Congress determined that the Federal Government was without authority to administer the trust directly, and, therefore, constituted an "establishment," whose statutory members are "the President, the Vice President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS

The membership of the Board of Regents remained unchanged during the current year. The roll of Regents at the close of the fiscal year was as follows: Chief Justice of the United States Earl Warren, Chancellor; Vice President Richard M. Nixon; members from the Senate: Clinton P. Anderson, J. William Fulbright, Leverett Saltonstall; members from the House of Representatives: Frank T. Bow, Overton Brooks, Clarence Cannon; citizen members: John Nicholas Brown, Arthur H. Compton, Robert V. Fleming, Crawford H. Greenewalt, Caryl P. Haskins, and Jerome C. Hunsaker.

As has been customary in recent years, an informal dinner meeting, preceding the annual meeting, was held on the evening of January 14, 1960, in the main hall of the Smithsonian Building amid exhibits from the various divisions showing the most recent developments in the work of the Smithsonian bureaus. Dr. James F. Cahill spoke on "The Chinese National Art Collection (Palace Collection) in

Taiwan"; Dr. Richard S. Cowan on "Smithsonian-Bredin Caribbean Expedition of 1959"; Dr. William C. Sturtevant on "Agriculture of the Seminole"; and Dr. Fred L. Whipple on "Scientific Results from Satellite Tracking."

The annual meeting was held on January 15, 1960. The Secretary presented his published annual report on the activities of the Institution together with the 1959 Annual Report of the United States National Museum. The Chairman of the Executive and Permanent Committees of the Board, Dr. Robert V. Fleming, gave the financial report for the fiscal year ended June 30, 1959.

In addition to the annual meeting, the Board of Regents met again on May 4, 1960. The Secretary presented a brief interim report, and the Chairman of the Executive and Permanent Committees of the Board presented a financial report. This meeting was followed by an inspection of some of the new exhibits of the Smithsonian.

FINANCES

A statement on finances, dealing particularly with Smithsonian private funds, will be found in the report of the executive committee of the Board of Regents, page 214. Funds appropriated to the Institution for its regular operations for the fiscal year ended June 30, 1960, totaled \$7,718,000. Besides this direct appropriation, the Institution received funds by transfer from other Government agencies as follows:

From the District of Columbia for the National Zoological Park-----	\$1, 165, 200
From the National Park Service, Department of the Interior, for the River Basin Surveys-----	122, 055

VISITORS

Visitors to the Smithsonian group of buildings on the Mall reached a total of 6,494,630, an all-time high and 143,000 more than the previous year. April 1960 was the month of largest attendance, with 1,070,709; May 1960 second, with 1,007,442; July 1959 third, with 941,397. Table 1 gives a summary of the attendance records for the five buildings; table 2, groups of school children. These figures, when added to the 951,608 recorded at the National Gallery of Art and the 4,059,804 estimated at the National Zoological Park, bring the year's total number of visitors at the Institution to 11,506,042.

TABLE 1.—*Visitors to certain Smithsonian buildings during the year ended June 30, 1960*

Year and month	Smithsonian Building	Arts and Industries Building	Natural History Building	Aircraft Building	Freer Building	Total
<i>1959</i>						
July-----	123, 735	355, 316	311, 489	135, 584	15, 273	941, 397
August-----	126, 971	377, 340	295, 634	8, 078	16, 183	824, 206
September----	52, 279	146, 086	117, 026	closed	8, 662	324, 053
October-----	54, 841	158, 749	109, 032	closed	7, 460	330, 082
November-----	45, 549	134, 169	113, 367	closed	6, 379	299, 464
December-----	29, 129	71, 139	79, 592	closed	5, 080	184, 940
<i>1960</i>						
January-----	36, 498	79, 557	86, 585	closed	6, 675	209, 315
February-----	38, 913	99, 156	88, 217	closed	4, 946	231, 232
March-----	43, 924	114, 124	106, 173	closed	6, 168	270, 389
April-----	174, 083	448, 872	348, 552	83, 571	15, 631	1, 070, 709
May-----	153, 306	388, 022	333, 461	118, 080	14, 573	1, 007, 442
June-----	160, 476	307, 504	229, 619	90, 755	13, 047	801, 401
Total-----	1, 039, 704	2, 680, 034	2, 218, 747	436, 068	120, 077	6, 494, 630

TABLE 2.—*Groups of schoolchildren visiting the Smithsonian Institution during the year ended June 30, 1960*

Year and month	Number of children	Number of groups	Year and month	Number of children	Number of groups
<i>1959</i>			<i>1960</i>		
July-----	21, 072	675	January-----	8, 898	289
August-----	8, 287	311	February-----	15, 236	378
September-----	3, 159	163	March-----	31, 626	807
October-----	16, 776	499	April-----	78, 896	1, 658
November-----	19, 292	515	May-----	94, 807	2, 052
December-----	10, 248	290	June-----	35, 723	812
			Total----	341, 020	8, 449

Report on the United States National Museum

SIR: I have the honor to submit the following report on the condition and operations of the U.S. National Museum for the fiscal year ended June 30, 1960:

COLLECTIONS

During the year 2,014,443 specimens were added to the national collections and distributed among the eight departments as follows: Anthropology, 57,202; zoology, 346,610; botany, 56,989; geology, 33,079; science and technology, 1,433; arts and manufactures, 1,075; civil history, 1,514,274; and Armed Forces history, 3,780. Included in the above total were 1,488,864 stamps, 215,686 insects, and 75,014 marine invertebrates. Most of the specimens were acquired as gifts from individuals or as transfers from Government departments and agencies. The Annual Report of the Museum, published as a separate document, contains a detailed list of the year's acquisitions, of which the more important are summarized below. Catalog entries in all departments now total 54,007,823.

Anthropology.—Among the items transferred to the Smithsonian Institution were a number of interesting ethnological objects presented to President Dwight D. Eisenhower during his recent eastern goodwill tour. Included was a full-size Iranian desk of Khatamkari inlay made by the foremost craftsmen in the reign of Reza Shad and used by him and the present Shah. An excellent Mende (Sierra Leone) helmet mask, complete with raffia fringe, of the type used in initiating girls into the Sande Society, was presented by Mrs. Virginia Pollak. Two hundred specimens from the Wai Wai Indians, living in British Guiana, collected by Dr. Clifford Evans, associate curator, and Dr. Betty J. Meggers, research associate, division of archeology, were turned over to the division of ethnology. Included in this unique collection are wooden stools, cassava graters, pottery vessels, articles of clothing and ornament, tools, weapons, and utensils.

Mrs. E. E. Daman of Louisville, Ky., presented a fine Chinese imperial dragon robe of the late Ch'ing dynasty. An excellent walrus-ivory cribbage board, carved in relief with human and animal motifs, collected near Nome, Alaska, was received from Mr. and Mrs. W. De Witt of Erie, Pa. Articles of Korean costumes made of colorful

silk brocade with subdued designs were donated by Lt. Col. and Mrs. G. W. Kelley of Alexandria, Va.

A special effort was made by the division of physical anthropology to incorporate in the collections the backlog of River Basin Surveys materials transferred from the Bureau of American Ethnology. The most outstanding transfer consists of 148 skeletons from the Sully site in the Oahe Reservoir, S. Dak., occupied in prehistoric times by the Arikara tribe. An important collection of 167 plaster-of-paris face masks of various peoples, mainly from Africa, acquired from Dr. Lidio Cipriani of Florence, Italy, help to fill in the ethnic gaps in the division's large group of face masks and busts. The Cipriani collection will also provide masks for display units in the exhibits modernization program. A new cast of the skull and lower jaw of the Skhül V, one of the Palestine Neanderthal specimens, was received as an exchange from the Peabody Museum, Harvard University. The Wenner-Gren Foundation for Anthropological Research presented a cast of the upper jaw of *Zinjanthropus boisei*, a lower Pleistocene australopithecine from Tanganyika. A bust of Dr. Aleš Hrdlička, late curator of the division of physical anthropology, sculptured by Milan Knobloch, was received as a gift from the National Museum Society in Prague, Czechoslovakia.

A total of 56,271 specimens was added to the collections of the division of archeology during the year. Objects from a prehistoric Oklahoma mound consisting of rare textiles, engraved conch shells, pottery vessels, native copper artifacts, pearls, stone pipes, and chipped stone comprised the outstanding acquisition. Other items came from the Spiro Mound site in Le Flore County, dating probably from the 13th or 14th centuries of the Christian Era and representing a high point in the ceremonial art of the Southeastern United States.

Zoology.—The division of mammals received 4,242 specimens comprising 50 accessions. Nearly half of this number came from Panama and the Canal Zone under a collecting program being carried out by Associate Curator Charles O. Handley in cooperation with the Gorgas Memorial Laboratory, units of the Department of Defense, and also individuals. Through Dr. Robert E. Kuntz, of the U.S. Naval Medical Research Unit No. 2, more than 300 mammals were received from Formosa. Dr. Robert Traub, of the Army Research and Development Command, contributed important collections from Malaya, Borneo, and western Mexico. The division also received specimens obtained in Indiana by Russell E. Mumford, Dwight M. Lindsay, and Ralph D. Kirkpatrick; in Lancaster County, Va., by C. O. Handley, Louis T. Dymond, and D. I. Rhymer; in Maryland by C. P. Lingebach; and in New Hampshire by Bernard Feinstein.

Two lots of Panamanian birds, comprising 1,313 bird skins, 93 skeletons, and 1 carcass, all collected by Dr. A. Wetmore, were ac-

quired by the division of birds. Other significant accessions were 749 skins, 43 skeletons, and 1 alcoholic specimen of North American birds transferred from the U.S. Fish and Wildlife Service; 246 birds from Formosa transferred from the U.S. Naval Medical Research Unit No. 2; 123 bird skins from Colombia by exchange with the Universidad Nacional de Colombia, Bogotá; and 236 birds from Bechuanaland and Southern Rhodesia obtained by purchase.

Small but noteworthy lots of reptile and amphibian material were received from areas previously unrepresented in the national collections. The most interesting of these are: 14 reptiles from Saudi Arabia, donated by Dr. R. L. Peffly; 6 reptiles from Swan Island near Honduras, transferred from the Coast and Geodetic Survey; and 23 specimens of *Leurognathus marmoratus*, a very rare species of salamander, from Georgia, the gift of Dr. B. S. Martof.

During the year 8,500 fresh-water fishes, collected by W. R. Taylor and R. H. Kanazawa in the southern Appalachians, and 2,285 deep-sea fishes from the western Atlantic, transferred from the Fish and Wildlife Service, were accessioned. A 15-foot thresher shark, a cast of which will be placed on exhibition, was donated by Harvey Bullis, Jr. This shark is unique because of its long tail.

The scale-insect (coccid) collection deposited by the Department of Entomology, Cornell University, estimated to contain about 50,000 specimens including many types, comprised the most important accession in the division of insects. The John S. Caldwell collection of nearly 13,000 lanternflies and psyllids and the Mark Robinson collection of 16,210 scarab beetles were also acquired. About 16,969 miscellaneous insects from various parts of the world were given by N. L. H. Krauss; O. L. Cartwright donated an additional 10,000 scarab beetles from his personal collection, and he also collected 2,774 specimens for the Museum; Dr. K. V. Krombein contributed 3,467 specimens of mostly Hymenoptera and Lepidoptera; and Dennis E. Puleston presented 2,764 miscellaneous arthropods collected by him in Tahiti.

This fiscal year was a record-breaking one for accessions of marine invertebrates. The most important and comprehensive of these are 6,900 shrimps and other invertebrates from the tropical and subtropical western Atlantic transferred from the Fish and Wildlife Service; a lot of 12,475 Antarctic invertebrates received from the Navy Hydrographic Office; about 2,400 identified medusae from the Arctic Ocean received from the Department of the Navy; more than 18,000 crustaceans from northern Alaska presented by Dr. E. E. Reed of Colorado State University; and over 24,000 crustaceans and other invertebrates, mostly from Lake Pontchartrain, received from Tulane University.

The Frances Lea Chamberlain bequest provided funds for the purchase of the C. R. Laws collection of about 12,500 mollusks assembled by one of New Zealand's outstanding malacologists. The second largest accession was a gift from W. E. Old, Jr., of 8,200 mollusks, representing many rare and otherwise important species. Two noteworthy collections of Pacific marine mollusks were received, totaling about 3,900 specimens.

Botany.—Among the important plant collections received as exchanges were 3,793 specimens from the Muséum National d'Histoire Naturelle, Paris, including 3,050 ferns, many of them isotypes, and valuable historic collections such as those of L'Herminier from Guadeloupe, Leprieur from French Guiana, and Bourgeau from Mexico; 5,808 plants of Indonesia from Herbarium Bogoriense, Bogor, Indonesia; and 2,582 photographs of type specimens received from the Chicago Natural History Museum. Other collections include 896 specimens acquired from the Texas Research Foundation, Renner, Tex., and collected by Dr. C. L. Lundell and Percy Gentle in Texas, Mexico, and Central America; 587 specimens received from the Gray Herbarium, Harvard University, and collected in Costa Rica by Miss Edith Scammon and in Peru by Dr. and Mrs. Rolla M. Tryon; and 162 plants of Israel from the Hebrew University, Jerusalem.

Gifts included 4,498 plants collected on Trinidad, Tobago, and other West Indian islands by Dr. Richard S. Cowan on the 1959 Smithsonian-Bredin Caribbean Expedition; 5,476 plants presented by Dr. José Cuatrecasas, collected by him in Colombia; 1,226 excellent specimens of Pennsylvania plants given by Muhlenberg College, Allentown, Pa.; 396 specimens, largely ferns, constituting the personal herbarium of the late Frank N. Irving, received from Mrs. Florence Skougard, Washington, D.C.; and 855 specimens collected in Santa Catarina, Brazil, by Rev. Pe. Raulino Reitz and R. Klein, received from the Herbário "Barbosa Rodrigues," Santa Catarina.

Curator C. V. Morton collected 1,395 plants in boreal Quebec and Ontario while on a field trip preceding the IX International Botanical Congress at Montreal; and Robert R. Ireland obtained on field trips 2,678 mosses from Virginia, Missouri, and Kentucky. Transferred from the U.S. Geological Survey were 1,868 plants of Polynesia collected by Dr. F. R. Fosberg and 1,348 plants of Alaska collected by Dr. L. A. Spetzman. Obtained from Dr. M. Jacobs, Leiden, Netherlands, were 611 plants collected by him in Borneo, and from the University of Zurich 615 specimens from New Caledonia.

Geology.—Among the important gifts received in the division of mineralogy and petrology are: A 740.25-carat carbonado diamond, French Equatorial Africa, from Diamond Distributors, Inc., the largest mass of black diamond in any museum in the United States and

possibly in the world; kurnakovite, Boron, Calif., from Arch Oboler; and a fine Australian opal weighing 25.5 carats, a part of the original Washington A. Roebling collection, from Mrs. Donald Roebling.

Outstanding among the mineral specimens received in exchange are: Arsenopyrite from Mexico, metaheinrichite from Oregon, inderite from California, the Ahlfeld collection of Bolivian minerals, and a selection from the Pennypacker collection of minerals of Cumberland, England. Newly described species acquired in exchange are: Strontioginorite, Germany; orthochamosite, Czechoslovakia; gastunite, Arizona; eardleyite, Utah; belyankinite and labuntsovite, U.S.S.R.

About 457 specimens were added to the Roebling collection by purchase from the Roebling Fund and by exchange. Among these the following are outstanding: Danburite, Mexico; apophyllite and spodumene, Brazil; and tourmaline, California. Among the specimens of outstanding exhibition quality added to the Canfield collection by purchase are: Corundum, Tanganyika; hemimorphite, Mexico; opal, Australia; hubnerite, Colorado; stibnite, California; and the newly described yoderite.

Gems acquired for the Isaac Lea collection by purchase through the Chamberlain Fund include a cat's-eye sillimanite from South Carolina; a tourmaline cat's-eye from Brazil weighing 76 carats; a 29-carat yellow apatite from Mexico; a 375-carat rose quartz from Brazil; a cut stone of microlite weighing 3.7 carats from Virginia; and a 48.2-carat colorless zircon from Ceylon.

Several meteorites new to the collection were received in exchange: Lillaverke, Varik, Laughalsen, Muonionalusta II, Ekeby, Follinge, Hedaskoga, and Homark, all from Sweden; Ramsdorf, Germany; Raco, Argentina; and Aswan, Egypt. A portion of the Al Rais, Saudi Arabia, meteorite was received as a gift from the Saudi Arabia Government, and W. S. Houston donated a portion of the Winkler, Kans., fall.

The most important gifts received by the division of invertebrate paleontology and paleobotany are: 600 Cambrian invertebrate fossils including types from the Wind River Mountains from Dr. Christina L. Balk; 2 lots of Cretaceous and Tertiary Foraminifera from Trinidad donated by Dr. Hans M. Bolli; 70 figured specimens of pelagic Foraminifera from the north and equatorial Pacific Ocean from Dr. John S. Bradshaw; 2,025 invertebrate fossils from eastern Fiji from the University of Rochester; 226 invertebrate fossils from MacKenzie Valley, Northwest Territories, Canada, from Alfred Lenz; 9 giant Eocene oysters from North Carolina from Eston Miller; 44 holotypes of Foraminifera from the Cretaceous and Lower Tertiary of New Jersey from R. K. Olsson; 56 Eocene crabs from Venezuela

from Dr. W. M. Furnish; and 13 type specimens of Mississippian sponges from Montana from Dr. R. C. Gutschick.

Funds from the income of the Walcott bequest permitted the purchase of 37 invertebrate fossils from Czechoslovakia, 1,095 specimens from the Pennsylvanian of Oklahoma, 189 invertebrates from Normandy, France, 35 rare brachiopods from Sicily, 1,146 Mesozoic echinoids from France, and 507 invertebrate fossils from Belgium.

Important exchanges received through the year included 160 Devonian invertebrate fossils from Northwest Territories, Canada, from Dr. W. G. E. Caldwell; 115 fossil mollusks and corals from the Island of Pavuvu in the South Pacific from James E. Conkin; and 1,100 Tertiary invertebrate fossils from Japan from Tohoku Imperial University.

Paleontological fieldwork by Dr. C. L. Gazin and Franklin Pearce under the Walcott Fund resulted in the collection of 200 fossil mammals from various Eocene strata of southwestern Wyoming. Among other outstanding additions to the vertebrate paleontology collections received as gifts are two record-sized tracks of carnivorous dinosaurs from Upper Cretaceous rocks in Utah, presented by the Kaiser Steel Corporation, and a unique skull of the Cretaceous fish *Anamognius zitteli* donated by Dr. J. Lloyd Watkins, Wichita Falls, Tex.

Science and technology.—An outstanding collection of 21 astrolabes was acquired by the division of physical sciences through the generosity of the International Business Machines Corporation. These instruments, representing the craftsmanship of Persia, India, North Africa, and Europe, date from the 13th to the 19th centuries. An equally elegant 16th-century instrument, presented by Lessing J. Rosenwald, is a folding sundial and compass to which several engraved maps and travelers' itineraries of central Europe have been added.

Other important additions included the magnetometer used by Alexander Dallas Bache at Girard College (1840-45), from the Carnegie Institution; the first cash register of James Ritty (1879), from the National Cash Register Co.; several examples of the first nylon produced, from E. I. du Pont de Nemours & Co.; and a replica of the experimental furnace used by Dr. Alwin Mittasch in connection with the development of the commercial synthesis of ammonia (1909-12), from the Badische Anilin and Soda-Fabrik AG.

The tools and machine of the famous American instrument firm of Wm. Bond & Son, Boston, were acquired by the division of mechanical and civil engineering. Included are a chronometer dated 1812, the first made in this country, and an example of William Bond's important invention, the chronograph. Other important acquisitions are a rare wooded-bed engine lathe of about 1830 and several lathes

and associated machine-shop fixtures of about 10 years later. These items were located in an abandoned Rhode Island shop through the help of Helen I. Fraser, of the New London Historical Society, and James Kleinschmidt, of Mystic Seaport, Conn.

Among a number of significant builder's half-models received by the division of transportation were two Cape Cod catboats from Marthas Vineyard, the gift of Manuel S. Roberts. The collections of the section of land transportation were augmented by the locomotive "Pioneer" and a Camden & Amboy Railroad coach from the Pennsylvania Railroad Co.

The division of electricity received from the National Bureau of Standards several wavemeters used in the standardization of radio equipment in the 1920's, and from the University of Michigan a Fleming cynometer and several early magnetrons. The Massachusetts Institute of Technology donated the G. H. Clark collection of documents and photographs on the history of radio.

Among the accessions acquired by the division of medical sciences are a 13th-century metal mortar and pestle made in Nishapur, Persia; an 18th-century microscope made by Dollond of London; a 19th-century set of brass Troy nested weights; and one of the earliest types of ionization chambers designed for practicing radiologists.

Arts and manufactures.—Among specially noteworthy fabrics acquired by the division of textiles are a collection of Jacquard-woven pictures, a 19th-century warp-printed scene requiring over 100 blocks to produce one repeat, and a roller-printed portrait on silk, all presented by Arthur E. Wullschleger. An interesting lot of 19th-century plush, beaded, and embroidered fabrics was presented by Dr. and Mrs. Leonard Carmichael. George C. Claghorn donated a hand-woven linen tablecloth. An unusual damask tablecloth, woven in 1860, with scenes from stories in the Old Testament, was presented by Mrs. Loren E. Souers. The first pair of experimental nylon hose made in 1937 and several bobbins of the early experimental nylon yarn were deposited by E. I. du Pont de Nemours & Co.

From Mrs. Dwight D. Eisenhower the division of ceramics and glass received a 13-piece porcelain tea set, produced about 1770 in Würtemberg, Germany, by the Ludwigsburg factory, one of the greatest of the 18th-century porcelain manufactories. The set was presented to President and Mrs. Eisenhower by His Excellency Theodor Heuss, President of the Federal Republic of Germany. Another generous gift of 102 pieces of American and European glass was received from Mrs. Clara W. Berwick. An outstanding art object in this group is a dark-blue glass plate with an enameled decoration taken from the 12th-century mosaic in one of the domes of St. Mark's Cathedral in Venice.

Among the particularly fine prints acquired by the division of graphic arts are an impression of a chiaroscuro woodcut, "David and Goliath," by one of the earliest masters of this art, Ugo da Carpi (1455-1523); two color etchings by Johan Taylor (1650-1700), the earliest pioneer in this medium; a large color mezzotint, "Cupid Shaping His Bow," by Edouard Gautier-Dagoty (1717-1785); and a chiaroscuro woodcut, "Pluto," by the Dutch artist Hendrick Goltzius (1558-1616). Outstanding gifts of the year included a collection of 255 portrait engravings by European artists of the 16th to 19th centuries presented by Col. and Mrs. Robert P. Hare, III, representing the work of such artists as Wierex, Bolswert, Leoni, Muller, Audran, and Nanteuil, and including contemporary portraits of such personages as Philip II, Charles I, Galileo, Sir Thomas Chaloner, and Thomas Carlyle.

Several specimens representative of the development of oilfield exploration equipment were acquired by the division of industrial cooperation, one of these being a 1925 Suess torsion balance. A portable pipeline pumping unit as developed by S. S. Smith of the Shell Oil Co., and first used in the North African campaign of 1942-43, was transferred from the Department of the Army. Among the items acquired for the hall of nuclear energy were a diffusion cloud chamber and a neutrino detection chamber, transferred with the cooperation of the National Science Foundation. Everett L. DeGolyer, Jr., presented a memento of his late father, Dr. Everett Lee DeGolyer, a pioneer in American oilfield development and a former Regent of the Smithsonian Institution. This electromagnetic detector for reflection seismographic exploration was developed by Dr. J. Clarence Karcher with Dr. DeGolyer's encouragement and is symbolic of the predominance of this technique in oilfield discovery since 1925.

A large number of farm implements and machines were acquired by the division of agriculture and forest products, many of which came from farms in Ohio. One of these is an early type of horse-drawn check-row cornplanter, donated by Clayton Kantner. Another is the Hart Parr tractor donated by the Oliver Corporation. This machine is the third tractor made by the Hart Parr Co., which commenced manufacturing in 1902. It symbolizes the switch from steam to gasoline on American farms and commemorates the general adoption of the name "tractor" as descriptive of gasoline traction engines. A companion piece to the big tractor is a Wallis Model K tractor donated by Massey-Ferguson, Inc. This model appeared in 1919 and is a modification of the 1913 Wallis Cub, the first of the frameless tractors. Another item is a McCormick "daisy" self-rake reaper donated by the Farmers' Museum of the New York State Historical Association.

Civil history.—The division of political history received a number of interesting donations. President Dwight D. Eisenhower presented a group of intricately carved figures, chariots, and horses, in ivory and sandalwood, representing a scene from the Mahabbarata, given to him by the President of India. Among the items given this year by Lincoln Isham were the gold-and-enamel bracelet worn by Mrs. Lincoln as First Lady and a black onyx lapel watch worn by her after the death of her husband. The dessert plates from the state china used at the White House during the administration of President James K. Polk were given by Mr. and Mrs. B. Woodruff Weaver. Additions to the collection of American period costumes included a wedding dress of about 1800, given by Mrs. Susan Iglehart; an 18th-century woman's brocade caraco jacket, presented by Mrs. James L. Collins, Jr.; and two dresses worn in Maryland in Colonial days, donated by Miss Katherine K. Scott.

From the family of Harry T. Peters the division of cultural history received the America-on-stone collection, comprising nearly 2,000 lithographs by printmakers other than Currier and Ives. Political cartoons, sporting pictures, and urban views are only a few of the many classifications in which the collection has authoritative representation. The Cooper Union Museum donated a group of 89 musical instruments, predominantly plucked-string instruments such as lutes and guitars, which were needed to supplement existing collections. An important transfer from the National Park Service comprises 37 pieces of mid-19th-century cast-iron architectural elements from the waterfront district of St. Louis.

Among important accessions received in the division of philately and postal history is the A. H. Wilhelm collection of United States plate number and position blocks of stamps of the period between 1894 and 1958. Nearly every printing plate used in the production of United States stamps is represented in all positions. An excellent reference collection of Japan's 1-sen value postage stamps of 1872 was donated by L. W. Christenson. John P. V. Heinmuller presented one album of Zeppelin covers, completing the transaction started last year. B. H. Homan, Jr., transferred his previously lent specimens of Saxony stamps as a gift. Supreme Court Justice John M. Harlan donated a considerable number of early United States covers extracted from the papers of his grandfather, Supreme Court Justice John M. Harlan (1833-1911).

The most important accession received by the division of numismatics is the collection of Russian coins and medals struck in the name of Czar Peter the Great, donated by Willis H. Du Pont. Mr. Du Pont also presented the 11 volumes of Grand Duke Mikhailovich's monumental and very rare monograph on Russian coins. The Grand

Duke's collection comprises a virtually complete representation of Russian bronze and silver coins struck since 1700, paralleled only by the Hermitage collection in Leningrad. Another noteworthy accession is the anonymous donation of 736 Canadian silver and copper coins, including the rare and famous 50-cent piece of 1921 formerly owned by King Farouk of Egypt.

Armed Forces history.—One of the three original 49-star flags prepared in advance of the new design was presented to the division of military history by President Dwight D. Eisenhower. Two exceptionally fine swords owned by Gen. Benjamin Lincoln of the Continental Army were received from one of his descendants, Mrs. Henry K. Cowen. One was carried by the General during the Revolution and the other was presented to him by General Washington after General Lincoln received the surrender of Lord Cornwallis at Yorktown.

Outstanding among the naval material received during the year was a collection of 134 builder's half-models of 19th-century warships, constituting a veritable national treasure by virtue of its exceptional scope, from the United States Naval Academy. Other notable accessions included models of the U.S.S. *Pennsylvania* (the birthplace of carrier aviation), the aircraft carrier *Shangri-La*, and the dirigible *Akron*; 13 oil paintings illustrating United States Coast Guard operations in World War II, from the Treasury Department; and a collection of relics of the Spanish American War and World War II, from the United States Coast Guard Academy.

The collections were further enhanced by the purchase of the W. Stokes Kirk collection of United States military insignia and accouterments, totaling approximately 3,000 items. It is considered by many authorities to be unmatched in scope, volume, and rarity.

EXPLORATION AND FIELDWORK

In connection with his participation in the 75th anniversary meeting of the Ohio Historical Society, April 27–May 2, at Columbus, F. M. Setzler, head curator of anthropology, examined several important archeological sites in Ohio, including Mound City, the Hopeton Works, Cedar Banks Mound, and the site of the original Adena Mound on the estate of the first Governor of Ohio, Thomas Worthington. While at Columbus he selected specimens from the study collections of the Ohio State Museum, to be cast for use in the modernization of the Smithsonian's North American Archeology Hall.

Dr. Waldo R. Wedel, curator of archeology, represented the Smithsonian Institution at the Darwin Centennial Celebration, held at the University of Chicago, November 24–26. This was an outstanding occasion, being attended by worldwide experts in various

fields of evolutionary philosophy who conducted and participated in panel meetings. The published results are sure to be of interest to all biologists and other scientists concerned in any way with evolution and its background. Subsequently, Dr. Wedel attended the 17th Plains Archeological Conference, in Lincoln, Nebr., where he reestablished contacts with many of the workers in the area of his principal interest, conferred with various archeologists of the River Basin Surveys, and examined recent archeological collections. Early in May Dr. Wedel attended the 25th annual meeting of the Society for American Archeology, at New Haven, Conn., presenting a paper on the progress of research in Great Plains prehistory. He also studied various important manuscripts in the Western Americana collections of the Yale University Library particularly relating to the Missouri River region and the Black Hills.

Dr. Clifford Evans, associate curator of archeology, and Dr. Betty J. Meggers, research associate, late in December attended the 58th annual meeting of the American Anthropological Association in Mexico City, where they delivered a paper on "Archeological Evaluation of Obsidian Dating." The gathering in Mexico City, they report, had the flavor of an international meeting, which left a favorable impression on delegates who seldom attend anthropological meetings outside the limits of the United States. The Mexicans were considerate hosts, and all visitors were highly impressed with the Institute of Anthropology and History and the various museums and exhibits in the Mexico City area. Following the meeting, Drs. Evans and Meggers spent several weeks in Mexico, examining archeological collections and sites in Tabasco, Chiapas, and Oaxaca, as well as the environs of Mexico City. Dr. Evans arranged to have certain important type collections sent to the Smithsonian, saw some archeological sites of major importance in Mesoamerica, familiarized himself with study and exhibit collections in several regional museums, and made contact with many colleagues.

Dr. Evans attended the 25th annual meeting of the Society for American Archeology at New Haven, Conn., May 4-7, and consulted with various archeologists involved in the Institute of Andean Research program seeking archeological connections between North and South America and Middle America. This group, including Drs. Evans and Meggers, will undertake an elaborate research program in the region during the next few years.

Dr. Evans and Dr. Meggers left on June 25 for extended study in various European museums, where they propose to do research on comparative archeological collections from North and South America. This work is undertaken in connection with their long-term program of archeological survey and excavation in the tropical forest region

of South America and is partially supported by a grant from the American Philosophical Society.

At a meeting of the American Oriental Society in New Haven, Conn., late in March, Dr. Gus Van Beek, associate curator of archeology, delivered a paper on one of his research projects, "The Multiple-piece Technique of the South Arabian Potter." While in New Haven he also studied the exhibits of the Peabody Museum and the Babylonian Collection in the Sterling Memorial Library, acquiring information about the technique of preparing impressions of seals which will be useful in the modernization of the Old World archeological exhibits. In May he worked in the library of the Johns Hopkins University, Baltimore, preparing a bibliography of major books and articles dealing with excavated archeological sites in the Republic of Sudan. This work has been useful in his research on the archeological potentialities of that part of the Sudan involved in the Nubia Salvage Project.

Dr. S. H. Riesenbergs, curator of ethnology, at the end of December attended the American Anthropological Association meeting in Mexico City, where he delivered a paper on "Political Advancement on Ponape: Theory and Fact." Subsequent to the meetings he examined collections in several museums and visited the archeological sites at Teotihuacan and the village of Toluca. Between February 28 and March 8, Dr. Riesenbergs furthered his Pacific ethnological studies by working at the Houghton Library of Harvard University and the Marine Historical Society and Whaling Museum at New Bedford, Mass. He was particularly concerned with examining and abstracting ethnohistorical materials from 19th-century manuscript records of the American Board of Commissioners for Foreign Missions. At New Bedford there exist similar records in the important collections of logs, journals, and manuscripts on early Pacific voyages. These library studies have enabled Dr. Riesenbergs to make further progress on his projected ethnohistorical study of the Carolines, which is part of his analysis of Micronesian culture.

Dr. Gordon D. Gibson, associate curator of ethnology, early in September did research at the American Museum of Natural History and the Museum of Primitive Art in New York. Subsequently he attended the meetings of the African Studies Associations at Boston University and did research in the study collections of the Boston Museum of Fine Arts and the Peabody Museum of American Archeology and Ethnology at Harvard University. The collection of African ethnological materials at the American Museum is an extensive one, and Dr. Gibson is discussing the possibility of arranging exchanges that would permit the Smithsonian Institution to improve its collections and provide material for a new exhibit hall in this

field. He especially studied collections from South West Africa and Angola, a region he expects to visit in 1960.

Late in December Dr. Gibson attended the annual meeting of the American Anthropological Association in Mexico City and presented a paper to the session on African ethnology on "Levels of Residence among the Herero." Subsequently, with several other delegates, he went to Palenque in Chiapas Province, an area of great interest anthropologically. The visitors examined the famous pyramid containing a tomb which is said to destroy the distinction formerly drawn between Egyptian and American pyramids. Until the discovery of this tomb, it had been stated that American pyramids were never tombs, but only the bases for religious structures. Dr. Gibson also examined anthropological collections in Mexico City.

In preparing for his forthcoming field trip Dr. Gibson visited New York and Cambridge, Mass., in March to investigate sources of field equipment. In Cambridge he consulted with Laurence Marshall, director of several expeditions in southern Angola and South West Africa, about problems of field maintenance and motion-picture work in those areas.

Dr. Eugene I. Knez, associate curator of ethnology, attended the annual meeting of the Association for Asian Studies in New York City, April 10-12. The scientific papers dealt with the people and cultures of southern, southeastern, and eastern Asia. In Cleveland, following this meeting, Dr. Knez examined the pipe collection of Dr. Leo Stoor and visited staff members of the Cleveland Museum of Natural History to discuss possible exchange of ethnological material.

Early in December, Dr. T. Dale Stewart, curator of physical anthropology, visited Guatemala to confer with staff members and advisers of the Institute of Nutrition of Central America and Panama. The problem involved was the planning of a 5-year program directed toward the investigation of atherosclerosis in Latin America populations. Dr. Stewart participated as a consultant in matters of race.

On December 26 Dr. Stewart went to Mexico City primarily to attend the meetings of the American Anthropological Association, where he delivered two papers—"The Evidence of Physical Anthropology Bearing on the Peopling of the New World" and "The Chinook Sign of Freedom: a Unique Record of Cranial Deformity." With other anthropologists he joined a tour to the Mayan ruin of Palenque, a ruin which makes it easier for an anthropologist to comprehend the problems surrounding the rise and fall of the Mayan civilization. He also visited Lake Patzcuaro in western Mexico, where he was able to observe living Tarascan Indians, a group which has figured prominently of late in the literature of physical anthropology.

In continuation of archeological research in Iraq, Dr. Stewart departed for that country on June 1. The 1960 Shanidar Expedition, jointly sponsored by the Smithsonian Institution and Columbia University, extends the collaboration between Dr. Stewart and Dr. Ralph S. Solecki, formerly on the staff of the division of archeology. Dr. Stewart plans to work at the Iraq Museum in Baghdad restoring, casting, and studying the adult skeletal remains recovered in 1957 by Dr. Solecki in the Mousterian layer of Shanidar Cave, and will then join the rest of the party at the Cave to help remove other remains.

Several members of the staff of the department of botany, Dr. Lyman B. Smith, Dr. Richard S. Cowan, Dr. Velva E. Rudd, C. V. Morton, and Dr. Mason E. Hale, Jr., with Dr. A. C. Smith, Director of the Museum of Natural History, participated in the IX International Botanical Congress in Montreal in August. This important Congress, which convenes only once every five years, in 1959 attracted more than 3,000 botanists from all parts of the world and was held in simultaneous sessions at McGill University and the University of Montreal. It was preceded from August 16 to 19 by meetings of the section of nomenclature, which involved several of the Smithsonian's botanists.

In May and June Dr. Lyman B. Smith, curator of phanerogams, visited several major herbaria in California in pursuit of his studies of the plant families Bromeliaceae, Xyridaceae, and Velloziaceae. He also studied a number of collections of living Bromeliaceae and of the genus *Begonia* in Los Angeles and conferred with various members of the Bromeliad Society and the American Begonia Society.

In June Dr. Richard S. Cowan, associate curator of phanerogams, visited several American museums to observe natural-history exhibits, to test audio-commentary systems, and to study exhibition techniques in connection with the proposed Hall of Plant Life at the Smithsonian.

Continuing her studies of the family Leguminosae, Dr. Velva E. Rudd, associate curator of phanerogams, visited several herbaria during the year. Following her attendance at the IX International Botanical Congress in Montreal, she spent three days at the New York Botanical Garden examining types and other specimens of genera closely related to *Ormosia*, and also the available Mexican material of papilionate legumes of the tribe Sophoreae. She made similar studies of the same groups at the herbarium of the Chicago Natural History Museum in connection with her attendance at the annual meeting of the American Association for the Advancement of Science in December. In May she spent three weeks at California herbaria examining plant specimens and accumulating data pertaining to a treatment of the papilionate legumes of Mexico.

In continuation of his studies of the large family Melastomataceae, Dr. J. J. Wurdack, associate curator of phanerogams, visited the New

York Botanical Garden in May, giving particular attention to the family as represented in the state of Santa Catarina, Brazil. To facilitate his continuing studies of the Melastomataceae, he borrowed numerous specimens for more detailed investigations.

During the first part of August, prior to his attendance at the IX International Botanical Congress in Montreal, C. V. Morton, curator of ferns, participated in a field trip to James Bay. This included explorations in the Laurentian forest, the boreal forest of northern Ontario, the Hudson Bay lowlands, and a part of the Great Lakes forest region. A collection of nearly 900 numbers, plus many duplicates, was obtained for the U.S. National Herbarium. Following his attendance at the Congress, Mr. Morton spent 10 days in the high Sierra Nevada of California collecting specimens for the Museum. Subsequently he visited herbaria in the San Francisco region, examining fern collections and conferring with staff members. Toward the end of the fiscal year Mr. Morton left for Europe to pursue his studies of various groups of ferns in several herbaria, beginning in the herbarium of the Muséum National d'Histoire Naturelle in Paris.

Between March 9 and April 11 Dr. Mason E. Hale, Jr., acting curator of cryptogams, journeyed to southern Mexico to collect lichens for a monographic revision of *Parmelia*. This expedition was sponsored in part by the National Science Foundation, and Dr. Hale was accompanied by Thomas R. Soderstrom, a graduate student from Yale University. During a 30-day period of uninterrupted work, the two botanists traveled about 2,500 miles in Veracruz, Chiapas, Oaxaca, and Michoacán, collecting approximately 2,200 numbers of cryptogams with many duplicates. This was the first significant exploration for cryptogams in southern Mexico, and many new distribution records, as well as discoveries of new taxa, were made. The specimens, which are now being prepared for study in Washington, will serve as a basis for specialized studies of cryptogams of the region and particularly as a partial basis for Dr. Hale's revision of the large and widespread genus *Parmelia*. During the first three days of June Dr. Hale visited the herbarium of Duke University to study lichen specimens and consult with colleagues on mutual problems concerning the genus *Parmelia*, in connection with his monographic revision.

In mid-July, Robert R. Ireland, Jr., assistant curator of cryptogams, collected cryptogams for the National Museum particularly in the Highlands area in the southwestern corner of North Carolina, and in the Great Smoky Mountains National Park on the North Carolina-Tennessee border. He obtained more than 800 specimens, mostly bryophytes, which will serve as a partial basis for his study of the moss flora of the southern Appalachians.

In December, Dr. Herbert Friedmann, head curator of the department of zoology, attended the meetings of the American Association for the Advancement of Science, in Chicago. As chairman of Section F, he gave an address on "Current Changes in the Environment of Zoological Research" at the zoologists' annual dinner. During the meetings he visited colleagues in the Chicago Natural History Museum and discussed problems of mutual interest in connection with his current research.

The detailed survey of the birdlife of the Isthmus of Panama under Dr. Alexander Wetmore, research associate and retired Secretary of the Smithsonian Institution, continued early in January in the tract of land on the Río Frijoles near Gamboa that, through a cooperative arrangement with the Naval authorities in the Canal Zone, is now available as an adjunct to the reserve on Barro Colorado Island. Dr. Wetmore spent the last half of January investigating several localities in the Pearl Islands in the Gulf of Panama. Collections made on the islands of Contadora, Chapera, Saboga, Cañas, Rey, Santelmo, Malaga, and Bayoneta yielded useful details of distribution. The remainder of the season from early February to the end of March he devoted to studies near the Costa Rican boundary in western Chiriquí. The main station, through the kindness of Pablo Brackney, was at the finca Palo Santo at 4,200 feet elevation, near the base of Cerro Picacho. From here collections were made through the plateau section at Tisingal, around the lakes and elsewhere, and in the mountains to an elevation of 7,500 feet on Volcán Barú. A brief visit to the Boquete area on the opposite side of the volcano added to the collections several species of birds not found previously. During the first part of March the work was concentrated on the lowland region below Concepción, where, through the friendly attention of Félix Espinosa, the party located on a finca at 2,200 feet elevation. Tracts of forest were accessible in the upper valley of the Río Escarrea. The main investigations were made lower down below Alanje, travel being by jeep over the sandy trails of the coastal plain. The work here extended across savanna country with occasional tracts of forest down to the seashore at Playa Barqueta and Ensenada Rica. At the end of March, with the season's work completed, the party returned to the Canal Zone.

With the cooperation of the Mexican Government, the Smithsonian-Bredin Expedition for 1960 undertook to collect for study and to report on specimens of the marine fauna and flora (algae) occurring along the coast of Yucatán from Progreso east and south to Espíritu Santo Bay, Quintana Roo. Five zoologists comprised the scientific staff: Dr. Waldo L. Schmitt, research associate, Dr. J. F. Gates Clarke, curator of insects, and Dr. Harald A. Rehder, curator of mollusks, all of the Smithsonian Institution; Dr. Franklin C. Daiber,

Department of Biological Sciences, University of Delaware, ichthyologist and ecologist, whose chief interest was in making an ecological study of a mangrove swamp and its associated fish population; and Dr. Edward L. Bousfield, curator of invertebrate zoology, National Museum of Canada, a carcinologist specializing on barnacles and amphipod crustaceans.

The expedition sailed on March 20 from Miami with Drs. Rehder and Schmitt and the expedition's collecting outfit, arriving in Progreso, Yucatán, a few days later. There Drs. Clarke, Daiber, and Bousfield joined the expedition, which departed on March 26 for Isla Mujeres, where they spent a few days gathering shallow-water animal life and algae. From here the party went to San Miguel, Isla Cozumel, for the first three days of April. At this locality they made collections on the coast and also along shore by diving and with the electric light and dipnet over the ship's side at night. They spent the next few days reconnoitering Espíritu Santo and Ascensión Bays and collected at the northern end of Cozumel from shore out to a depth of two fathoms, by diving, and also at Punta Molas, near the lighthouse, and in the shallow brackish lagoon at the northern end of Cozumel.

The period April 10 to 19 was devoted primarily to Dr. Daiber's ecological study of portions of the great mangrove swamp in Ascensión Bay. Concomitantly extensive invertebrate and entomological collections were made on land and along shore in the vicinity of the lighthouse, in the swampy areas, on the far shore of the Bay, and at the northern end of the reef where it joins the mainland. The shoal waters of the south end of Cozumel Island, particularly about Punta Santa María, also were explored.

Members of the party flew to Mérida on April 24 to meet J. Bruce Bredin, sponsor of the expedition, and Ernest N. May, both of Wilmington, Del. Although Drs. Clarke and Bousfield had to leave the expedition at this point, the rest spent April 25 to 27 visiting the Maya ruins at Chichén Itzá, and on April 28 those at Uxmal, returning to Cozumel on April 30. They then departed for Georgetown, Grand Cayman, and after a limited period of collecting on this island, returned to Miami on May 7.

In the course of the six weeks' expedition 119 collecting stations were established, mostly in the marine littoral, and 15 plankton samples were made with tow and dipnet, the latter with the aid of a submerged electric light over the ship's side. Dr. Clarke at 20 different places collected insects, along with other terrestrial arthropods, and, on Cozumel, a number of bats. The number of marine invertebrates obtained may total 10,000. Many of these are small, some of even microscopic size. Over 500 specimens of fishes were caught, and in excess of 5,000 insects and terrestrial arthropods were preserved.

Scientifically, the present expedition may be counted as one of the more productive of the recent expeditions under the sponsorship of Mr. and Mrs. Bredin. The collections of the Smithsonian Institution have been greatly enhanced by this important collaboration.

Dr. David H. Johnson, curator of mammals, visited the California Academy of Sciences in San Francisco, June 13-14, to obtain data for the proposed dugong group in the new Hall of Oceanic Life of the Museum of Natural History. He also studied the collections of mammals in the Academy, finding significant specimens from Annam, Korea, and Manchuria bearing upon his research projects. Subsequently, Dr. Johnson attended the annual meeting of the American Society of Mammalogists in Tacoma, Wash., where he had an opportunity to review with colleagues the manuscript report on mammals collected on Ponape in connection with a project of the Pacific Science Board.

Dr. Henry W. Setzer, associate curator of mammals, spent the first few days of December at the American Museum of Natural History, where he familiarized himself with some of the collections of the department of mammals. His particular interest was to make a survey and a study of African mammals, particularly those belonging to the genus *Acomys*.

Dr. Charles O. Handley, Jr., associate curator of mammals, made a brief trip to Fenwick Island, Del., to obtain for the National Museum a skull of a young male beaked whale, *Ziphius cavirostris*, a species rarely collected. Later in September he spent five days in Virginia near the mouth of the Rappahannock River, in order to augment the collection he made in this mammalogically little known area in May 1959. He collected approximately 70 mammals, many of which are significant in working out the relationships of the mammalian fauna of this isolated area, and some of which are rare in Coastal Plains collections.

During the first week of December Dr. Handley made a very productive study trip to the Academy of Natural Sciences at Philadelphia, the Museum of Comparative Zoology of Harvard University, and the American Museum of Natural History in New York, his objective being to compare recently acquired Panamanian specimens with types and other specimens in the respective museums. He was able to develop a large body of valuable notes, and it was discovered, surprisingly, that several of the species represented in the Panamanian collections are apparently undescribed.

Between January 12 and March 15, Dr. Handley, accompanied by D. I. Rhymer, of the taxidermy shop, continued his survey of the mammals of Panama, which is now in its fourth year. This work is being conducted in cooperation with the Gorgas Memorial

Laboratory. Collecting in Panama this year was entirely in the province of Bocas del Toro, on the Caribbean coast adjacent to Costa Rica, a region of heavy rainfall without a distinct dry season. Collections were made in the great swamps around Almirante and Boca del Drago and at a cattle ranch near Changuinola. One of the bats obtained is the third known specimen of a species last collected in 1896, while another had previously been known only from southern Mexico and southeastern Brazil. Several of the marsupials and rodents appear to be undescribed subspecies, and at least two of the birds were second records for Panama.

From mid-March to mid-April Dr. Handley and Mr. Rhymer worked in Venezuela in cooperation with the Ministry of Agriculture of that country, with headquarters in the National Park of Rancho Grande in the coast range about 50 miles west of Caracas. They sampled the desert fauna along the Caribbean coast, the cloud forest on the mountaintops, and the arid savannas around Lake Valencia in the interior. Most of the species obtained in Venezuela have been poorly represented in the U.S. National Museum. Several of the bats and one of the mice have not previously been reported in Venezuela; one of the bats, although common locally, is the second known collection of the species, recently described from Panama. During the course of their work in Panama and Venezuela in 1960 Dr. Handley and his assistant collected and preserved more than 2,500 specimens of mammals, birds, reptiles, and amphibians, in addition to a number of invertebrates and a few fishes. This significant material includes several species new to the collections of the National Museum and many others representing extensions of known geographical ranges.

In his capacity as secretary of the American Ornithologists' Union, Herbert G. Deignan, associate curator of birds, attended the annual meeting at Regina, Saskatchewan, toward the end of August.

Dr. Leonard P. Schultz, curator of fishes, made a trip to Miami, Fla., and Bimini, Bahamas, July 6-11, for the purpose of locating molds and casts of large fishes for the proposed Hall of Oceanic Life. On October 30 he attended the dedication services for the new building of the Bingham Oceanographic Laboratory at Yale University and while there made extensive notes on fish specimens available for study, with special attention to sharks and various reef-fishes.

Between August 26 and September 5, Dr. William R. Taylor, associate curator of fishes, and Robert H. Kanazawa, museum aide, collected fishes in the Tennessee River and adjoining river systems in Virginia, Tennessee, Georgia, and Alabama, a particular desideratum being specimens of fishes of the genus *Noturus* needed for a revision by Dr. Taylor which is nearing completion. Important ecologi-

cal and locality data also were obtained. Continuing their studies, the two made a similar collecting trip to the Neuse and Tar River systems of North Carolina, September 16-20. The species under particular consideration there was *Noturus furiosus*, of which nearly 100 specimens were obtained from three localities in the Tar River system, thus increasing the number of known specimens many times and adequately meeting the needs of the study in progress. These two expeditions resulted in the addition of about 8,500 specimens of fishes to the collections of the U.S. National Museum.

O. L. Cartwright, associate curator of insects, in December made a research trip to the Academy of Natural Sciences at Philadelphia comparing specimens and examining holotypes of four species of *Onthophagus*, a group of scarab beetles he is revising.

Dr. Ralph E. Crabill, Jr., associate curator of insects, continued his work on chilopods by studies at the Museum of Comparative Zoology, at Harvard University, July 20-25. He studied specimens housed in the collection, attempted to collect topotypes of an obscure species described from that area, and conferred with colleagues concerning biological and curatorial problems. With the aid of a National Science Foundation grant Dr. Crabill left Washington on March 28 for an extended study of centipedes and millipedes in European museums. He was accompanied by Dr. Richard L. Hoffman, research assistant, who is a specialist on millipedes.

Between September 26 and October 4, Charles E. Cutress, Jr., associate curator of marine invertebrates, traveled to Buxton and Beaufort, N.C., to examine collections of sea anemones at the Cape Hatteras and Duke Marine Laboratories and to collect and photograph sea anemones in both areas. Specimens and notes obtained made it possible to settle problems concerning the anemones of the area.

In continuation of studies on the Pacific marine fauna undertaken under a contract with the Atomic Energy Commission and the Office of Naval Research, Dr. Harald A. Rehder, curator of mollusks, studied collections in Cambridge, Mass. In studying the Pacific mollusks he is being assisted by Dr. Joseph Rosewater, research assistant. Studies were made in the Museum of Comparative Zoology; in particular, specimens of the Tellinidae from the Indo-Pacific area were critically examined and recorded in order to facilitate the preparation of a monograph on the members of this large family. Dr. Rehder also visited Salem, Mass., to confer with Dr. Donald Marshall, an ethnologist of the Peabody Museum, who during the course of his fieldwork has made extensive collections of mollusks in the Tuamotus that are of considerable interest to Dr. Rehder in connection with his Pacific studies. Dr. Rosewater examined approximately 270 lots of specimens of the molluscan family Pinnidae at the Museum of Comparative

Zoology and at the Academy of Natural Sciences of Philadelphia in furtherance of a monograph on the Indo-Pacific species of this family.

In mid-February Dr. Joseph P. E. Morrison, associate curator of mollusks, acted as one of the judges of the annual show of the St. Petersburg, Fla., Shell Club. The Smithsonian Institution offers an annual citation for the best exhibit in this display. Subsequently, he carried on some dredging operations in the upper end of Old Tampa Bay, and at Long Bayou he found living *Polymesoda* clams in the black muck under grass in the intertidal zone, where the local shell collectors had previously seen only dead shells.

The month prior to June 15 Dr. Morrison, accompanied by James Watson of the exhibits staff, spent at two southeastern localities photographing, sketching, and collecting specimens and materials for shore-line habitat groups for exhibit in the proposed Hall of Oceanic Life. Included were more than two weeks at the Gulf Coast Research Laboratory at Ocean Springs, Miss. On the return trip they visited the University of North Carolina Institute of Fisheries Research, at Morehead City, N. C., and gathered materials and specimens for the sand-beach shore-line group. The superb cooperation of the personnel concerned at both of these laboratories made possible the virtual completion of this complicated work in considerably shorter time than was originally planned and the gathering of additional scientific specimens of mollusks and other animals at various other localities. For example, previously unknown egg characters and new locality records of fresh-water mollusks were obtained from Virginia, Tennessee, and Georgia on the way south. Several species and genera were added to the known molluscan fauna of Mississippi, and topotype specimens of the brackish-water snail genus *Littoridinops* were obtained from near Darien, Ga.

From July 6 to August 7, 1959, Dr. G. A. Cooper, head curator of the department of geology, and Dr. Richard E. Grant, research assistant, conducted fieldwork in west Texas in furtherance of their studies of fossil brachiopods, a long-term project that is partially supported by a grant from the National Science Foundation. They made extended stays in the Glass Mountains, the Chinati Mountains, the Sierra Diablo, and the Carlsbad Caverns area. The expedition was a success in every way, and many fine blocks containing important fossil brachiopods were obtained that will yield much new information and permit the correction of possible errors in earlier records. In mid-June Dr. Cooper visited the American Museum of Natural History to study a large and valuable collection of fossil corals, some of which are being offered to the National Museum.

Between August 17 and September 10 Dr. George S. Switzer, curator of mineralogy and petrology, visited several institutions in Europe to examine their mineral collections and discuss future exchanges with staff members. Subsequently, he attended the first general assembly of the International Mineralogical Association in Zurich, where he represented the Mineralogical Society of America, and a meeting of the Museums Commission of the International Mineralogical Association. This highly successful international session was followed by a 4-day field excursion to classic mineral localities in the Swiss Alps. During the week following March 4 Dr. Switzer visited Dr. Mark C. Bandy, of Phoenix, Ariz., to examine a collection of several thousand mineral specimens comprising an exceptionally valuable study set of South American minerals, especially from the tin mines at Llallagua, Bolivia.

In September E. P. Henderson, associate curator of mineralogy and petrology, accompanied by Grover C. Moreland, physical science aide, visited the Battelle Memorial Institute in Columbus, Ohio, to study the techniques developed there for polishing metals, ores, and meteorites. Mr. Henderson also examined specimens of the New Concord meteorite in the Ohio State University Museum and some of the Hopewell material in the Museum of Archeology. In connection with the annual meetings of the Geological Society of America in Pittsburgh, November 1-12, he visited the Mellon Institute and discussed exchanges of meteorites and tektites with staff members. Subsequently, he discussed problems pertaining to meteorites with staff members of the Chicago Natural History Museum and the University of Chicago.

Long interested in the study of tektites, Mr. Henderson has been attempting for some years to acquire a representative collection of these interesting extraterrestrial objects for the Smithsonian Institution. One of the principal collectors has been Dr. H. Otley Beyers, of Manila, who has perhaps the largest privately owned tektite collection in the world. Aided by a grant from the National Science Foundation, Mr. Henderson left Washington late in January to select from this collection, with Mr. Beyers's cooperation, representative material for the Smithsonian. He spent nearly two months in Manila at this task, and as a result approximately 10,000 specimens will come to the Institution as a donation by Dr. Beyers. These very valuable specimens will greatly augment the material available in the United States for study by specialists. After completion of his work in the Philippines, Mr. Henderson visited 15 institutions in Viet Nam, Thailand, Burma, India, Russia, Austria, Switzerland, Germany, France, and England, becoming acquainted with specialists on meteorites and tektites and making preliminary arrangements concerning

exchanges between the Smithsonian Institution and these various other museums.

In mid-November Paul E. Desautels, associate curator of mineralogy and petrology, visited Rochester, N.Y., to select specimen materials for the national collections. At the request of the Rochester Academy of Sciences he gave a talk at the Rochester Museum of Arts and Sciences entitled "Crystal Growth and Its Aberrations in Mineral Crystals."

In June he went to the southern Illinois-Kentucky fluorspar mining district, in the hope that certain deficiencies in the museum collections could be eliminated. The trip proved very successful, resulting in the acquisition of about 1,000 pounds of top-quality mineral specimens of fluorite, calcite, barite, galena, and quartz.

On June 1 Dr. Richard S. Boardman, associate curator of invertebrate paleontology and paleobotany, left for an extended visit to Europe to facilitate his studies of fossil Bryozoa of the United States and their correlation with European faunas. This research is partially supported by a grant from the National Science Foundation. Dr. Boardman's objectives are to collect Ordovician fossils, mainly Bryozoa, and to visit museums and universities in Great Britain, France, Belgium, Germany, and other continental countries.

Dr. Porter M. Kier, associate curator of invertebrate paleontology and paleobotany, spent the period October 11-16 collecting fossil echinoids on the Chattahoochee River and its tributaries in Georgia, accompanied by Dr. Norman Sohl, of the U.S. Geological Survey. The geologists visited all the known echinoid localities in the area and acquired many excellent specimens for the collections of the National Museum. In November and in March Dr. Kier visited the Academy of Natural Sciences in Philadelphia and the Museum of Comparative Zoology at Harvard University to study the fossil and recent echinoid collections of those institutions. Many specimens were seen, and some were borrowed in aid of his work on the Cassiduloida, an order of sea-urchins. On June 6 he departed for a brief European trip, during which he intends to examine collections of fossil echinoids in the museums at Paris and Liège. This study, which is part of a project supported by the National Science Foundation, is to aid in the preparation of a monograph on the Cassiduloida.

Dr. Richard Cifelli, associate curator of invertebrate paleontology and paleobotany, joined a group of biologists from the Woods Hole Oceanographic Institution in marine studies from August 5 to 19. After preliminary work at Woods Hole, Mass., the group went to Bermuda, whence, aboard the oceanographic vessel *R. V. Chain*, they sailed on a more or less direct line to Woods Hole, stopping at 15 stations along the way. They made hydrographic observations and took

200-meter oblique plankton tows at each station. Also at each of the stations they took a separate tow for pelagic Foraminifera, using a specially designed $\frac{1}{2}$ -meter net with a guard at the forward end. This is a particularly interesting traverse because it crosses diverse water masses, including the Sargasso Sea, the Gulf Stream, the North Atlantic Slope Waters, and the Eastern North Atlantic Coastal Waters. Each water mass appears to be characterized by a distinctive assemblage of Foraminifera. From this and further scheduled trips Dr. Cifelli expects to gather more data on the distribution of North Atlantic pelagic Foraminifera and on factors responsible for their distribution.

During the first half of June Dr. Cifelli, accompanied by several members of the U.S. Geological Survey and the Canadian Geological Survey, visited several western States to examine important marine Jurassic sections. The party studied the Jurassic stratigraphy at sites in Wyoming, Montana, and Idaho. Dr. Cifelli collected 130 foraminiferal samples from the shales in the Jurassic formation.

Henry B. Roberts, museum aide, in mid-January visited the Academy of Natural Sciences at Philadelphia to study various primary types of fossil decapods and barnacles. The Academy's collections in these fields contain important historical material particularly useful to Mr. Roberts in his researches.

Dr. C. Lewis Gazin, curator of vertebrate paleontology, accompanied by Franklin L. Pearce, exhibits specialist, devoted about a month early in the year collecting fossil vertebrates in southwestern Wyoming and adjacent Utah. Dr. Gazin traced the Sage Creek White Layer, which marks the boundary between the upper and lower Bridger formation from the type section of Cottonwood Creek around the basin to its most easterly point on Twin Buttes. This study has considerable significance in properly correlating many of the collections made from various localities in earlier years and correcting errors on a map prepared by Matthew and Granger about 50 years ago. Collecting was largely concentrated in the lower or Bridger "B" levels on both sides of the basin, but localities visited outside the areal extent of the Bridger formation included a lowermost Eocene fossil occurrence just south of Bitter Creek Station on the Union Pacific Railroad, a previously very productive locality for lower Eocene mammals, about 12 miles north of Big Piney, Wyo., and a series of nearly barren upper Eocene exposures in Norwood Canyon, Morgan County, Utah.

After the completion of his fieldwork, Dr. Gazin studied fossil primates at the Los Angeles County Museum. Later, September 10-12, in Salt Lake City, he participated in the annual field conference of the Intermountain Association of Petroleum Geologists. Between

December 6 and 13 he visited research collections at Princeton University and the American Museum of Natural History to study Eocene creodonts, primates, and rodents. In both institutions he found many valuable specimens bearing upon his current studies, and paleontological problems were discussed in detail with various staff members. In mid-April Dr. Gazin began an extended tour of various European countries to carry on both museum research and fieldwork. Beginning in France and Switzerland, he will continue this work in Germany, Austria, Denmark, Belgium, and England, the primary purpose of the project being to study early Tertiary mammalian collections and to visit the more important classical localities for early fossil mammals. It is part of a long-term research project on the early Tertiary mammals of North America, which is partially supported by a grant from the National Science Foundation.

Late in May Dr. David H. Dunkle, associate curator of vertebrate paleontology, spent a week first at the Carnegie Museum in Pittsburgh studying examples of Mesozoic fishes from Europe, especially amioids and oligopleurids, and then at the Cleveland Museum of Natural History consulting staff members on the reconstruction of dinosaur skeletons in their new hall with a view to obtaining information of use in the renovation of halls in our Museum of Natural History.

Dr. Nicholas Hotton III, associate curator of vertebrate paleontology, spent the last week of October examining deposits of Dunkard (Permo-Carboniferous) age in Belmont County, Ohio, for vertebrate remains. The outcrops visited were those used by members of the U.S. Geological Survey in stratigraphic studies of Monongahela and Dunkard rocks of that county. He collected vertebrates from 15 localities from which material had not been previously obtained. Dunkard outcrops in western West Virginia and more northerly exposures of the Dunkard in Ohio and Pennsylvania were also studied. Subsequently, Dr. Hotton spent some time at the Carnegie Museum, in Pittsburgh, examining collections of Dunkard material, and attending the annual meetings of the Society of Vertebrate Paleontology and the Geological Society of America. In connection with the planned renovation of the Dinosaur Hall in the Museum of Natural History, Dr. Hotton spent about 10 days in November visiting comparable presentations in the American Museum of Natural History, the Yale Peabody Museum in New Haven, the Cleveland Museum of Natural History, and the Chicago Natural History Museum. The arrangement of dinosaur skeletons and certain lighting effects achieved at these institutions provided him with useful background information for planning the Smithsonian's new exhibits. During the last week of March Dr. Hotton worked at the Museum of Comparative Zoology at Harvard University, examining and making sketches of specimens of

primitive members of the reptilian order Captorhinomorpha, in connection with his research on the nature and origin of the reptilian middle ear. The skulls inspected display important morphological detail which has not yet been recorded.

For a month and a half just before the end of the fiscal year, Dr. Hotton, accompanied by John D. Gassaway, museum aide, collected in the Permian areas of Kansas, Oklahoma, and Texas. They explored outcrops of the Speiser formation for vertebrate fossils from Riley County to Cowley County, Kans., and obtained a good collection of little-known amphibians, including the greater part of an excellently preserved articulated skeleton of *Acroplous*. Most of the well-known localities in Texas appear to have been overcollected, but nevertheless some interesting blocks containing bones of many small animals were obtained in new localities or less promising areas around the better-known ones. A marked difference between the Kansas and Texas deposits was noted, although they are roughly of the same age.

Exhibits Specialist Franklin L. Pearce spent ten days in June at the Cleveland Museum of Natural History, the University of Michigan Museums, and the Chicago Natural History Museum, primarily to observe their methods of preparation of fossils and the use of new plastic and metallic materials in the field of vertebrate paleontology. Some of the new techniques utilized in these museums hold promise for use in the restoration procedures already in progress at the Smithsonian.

The Director of the Museum of History and Technology, Frank A. Taylor, spent two days in New York in July at the American Museum of Natural History and the Metropolitan Museum of Art investigating details of exhibition techniques. He examined reproductions of early European mechanical calculators and met the craftsmen who are building the model of the da Vinci coining press for the Smithsonian.

Dr. Robert P. Multhauf, head curator of science and technology, made trips during the year to several of the eastern States, visiting museums, other institutions, and individuals to examine scientific apparatus and antique instruments of possible interest to the Smithsonian study and exhibits programs.

In order to accelerate the enlargement of exhibit and study materials of the division of mechanical and civil engineering, Eugene S. Ferguson, curator, visited a number of institutions and individuals throughout the eastern United States. Especially at Winterthur, Del., Philadelphia, and various localities in New England, he acquired information about specific machines and tools of potential use in planning various new Smithsonian exhibits. In June he attended

the 68th annual meeting of the American Society for Engineering Education at Purdue University and presented a paper on "Kinematics of Mechanisms from the Time of Watt."

In connection with planned halls in the new Museum of History and Technology, Edwin A. Battison, associate curator of mechanical and civil engineering, visited various watch factories, collections, and individuals throughout the northeastern States. He examined many chronometers and watches as well as certain historical instruments with a view to acquiring material and information for the Institution.

During the year Robert M. Vogel, assistant curator of mechanical and civil engineering, made several trips throughout the northeastern States in connection with the exhibits in the new Smithsonian Hall of Engineering. He examined a large quantity of mechanical equipment including elevators, engines, railroads and other means of transportation and made many contacts with interested individuals and developed plans for the acquisition of desired specimens for the new hall.

In the continuing development of a program for the construction of models for the new Museum of History and Technology, Howard I. Chapelle, curator of transportation, spent May 16-24 visiting individuals and model manufacturers throughout the northeastern States. Included were such public organizations as the Museum of the City of New York and the New Bedford Whaling Museum, where he inspected builders' models of ships.

John H. White, Jr., assistant curator of transportation, made trips to several eastern States where he visited institutions, libraries, and individuals to examine historic locomotives and models and other railroad equipment, as well as catalogs and documents.

During the year W. James King, Jr., acting curator of electricity, visited various museums and libraries throughout the eastern States, primarily in connection with Smithsonian study collections and the proposed new Hall of Electricity. He studied collections in telephone communications, the various aspects of telegraphy and electronic equipment, and the history of electrical technology and engineering.

Dr. John B. Blake, curator of medical sciences, made several short trips to examine historic medical instruments and X-ray apparatus with a view to enlarging and improving the Smithsonian collections in this field. Between March 30 and May 15, he visited numerous museums, universities, and other institutions in Great Britain, Holland, France, Switzerland, Italy, Germany, Denmark, and Sweden, principally those containing objects pertaining to medical history. The historical medical museums in London, especially the Wellcome Historical Medical Museum, and in Zurich, Rome, Copenhagen, and

Stockholm were particularly outstanding. He also furthered his research in dental history in the study collections of these museums.

Early in December Dr. Sami K. Hamarneh, associate curator of medical sciences, visited the Firestone Library at Princeton University, the College of Pharmacy and Science in Philadelphia, and the chemistry department of the University of Pennsylvania to study Arabic manuscripts pertaining to health arts, to consult oriental published works contained in these various libraries, and to examine pharmaceutical antiques housed there.

Dr. Philip W. Bishop, head curator of arts and manufactures, spent two days in West Virginia in November inspecting certain early oil-pumping equipment. He made a number of contacts with oil- and gas-well owners which may lead to further acquisitions for the exhibits of the Museum of History and Technology.

In November Miss Grace L. Rogers, acting curator of textiles, spent three days in New York City visiting various textile establishments. She also visited the Fabien Printing Co. in Lodi, N.J., where with expert guidance she examined in detail the various steps in both the screen-printing and roller-printing processes. In May she attended the first International Textile Machinery Exhibition sponsored by the American Textile Machinery Association, at Atlantic City, N.J., where exhibits from 11 foreign countries and the United States were on display that incorporated new ideas in textile machinery.

Several trips to museums and other institutions and individuals were made during the year by Paul V. Gardner, acting curator of ceramics and glass, for the purpose of acquiring materials for Smithsonian exhibits. These included visits to the Corning Museum of Glass, the Syracuse Museum of Fine Arts, the New Haven Colony Historical Society, and the New Historical Society.

Jacob Kainen, curator of graphic arts, spent five days in September in Minneapolis checking data on John Baptist Jackson and Hendrick Goltzius, particularly at the Minneapolis Public Library, the Minneapolis Art Institute, and the Walker Art Institute. In December he visited various museums and libraries in Richmond, Va., and Raleigh, N.C., in pursuance of the same research projects pertaining to these artists.

In April, Fuller O. Griffith, 3d, assistant curator of graphic arts, studied a collection of Hassam lithographs in the Detroit Institute of Arts. He found several unique examples of Hassam's work that were of great interest and value in furthering his research on this artist.

Charles O. Houston, Jr., associate curator of industrial cooperation, made two trips to Pittsburgh during the year to visit the

Bureau of Mines, the Carnegie Library and Museum, and other institutions to study references on mine technology and coal-cutting machinery. An examination of operations connected with the preparation and shipment of various kinds of coal at the Mathies Mine on the Monongahela River was useful to Mr. Houston in his preparation of plans for the new Smithsonian Hall of Coal.

At a meeting of the Agricultural History Society at Louisville, Ky., E. C. Kendall, associate curator of agriculture and wood products, discussed the acquisition of various farm implements to supplement such collections in the Museum of History and Technology and gave a paper on 18th-century American plows and their European origins.

Dr. Anthony N. B. Garvan, head curator of civil history, made several trips in connection with the preparation of a new hall, The Growth of the United States. Among the institutions visited, and from which valuable information and suggestions were obtained, were the Hispanic Society of America in New York, the Academy of Natural Sciences of Philadelphia, and the Ford Museum in Dearborn, Mich. In May Dr. Garvan attended a meeting of the Board of the Human Relations Area File in New Haven. The Smithsonian Institution has recently acquired a set of these valuable files and has been elected to membership. This research material will be of value to members of the Smithsonian staff and to other scientists in the Washington area.

Dr. Wilcomb E. Washburn, curator of political history, visited several eastern museums and other institutions in continuance of his studies of political Americana and to review exhibit techniques in use elsewhere. At several historical houses he examined collections referring to American historical figures, including William Henry Harrison, Henry Clay, Abraham Lincoln, William Seward, and Franklin D. Roosevelt.

During several trips to various parts of the eastern States, C. Malcolm Watkins, acting curator of cultural history, examined many collections in connection with the proposed halls of the Museum of History and Technology. In the Virginia State Library, in Richmond, and in the Archives of Colonial Williamsburg, he continued his research on the Marlborough site.

John D. Shortridge, associate curator of cultural history, attended the sessions of the American Musicological Society in Chicago late in December. He visited the Chicago Art Institute and the Newberry Library, to examine harpsichords and other musical instruments of historical interest.

Rodris C. Roth, associate curator of cultural history, went to New York and New England in November to study period rooms and decorative arts collections in various museums and galleries. Her

research involves studies in visual materials, such as painting and prints related to American and English interior decoration of domestic dwellings in the 17th, 18th, and 19th centuries. Her studies outside of Washington have enabled her to advance projects on furnishings and exhibits for a Smithsonian hall of Every Day Life in the American Past.

John N. Pearce, assistant curator of cultural history, visited Wilmington, Del., and New York City in April and May to carry out research on the Meeks family, cabinetmakers in New York in the 18th and 19th centuries.

George T. Turner, acting curator of philately and postal history, accompanied by Francis J. McCall, associate curator, attended the 11th annual American Stamp Dealers' Show in New York, November 18-22. A 12-frame display prepared by the division of philately and postal history was exhibited and aroused much interest. Mr. McCall, while in Boston in September, continued research on the establishment of a post office in the Colony of New England; he also examined Hawaiian missionary correspondence of the period 1820-50 in the Houghton Library of Harvard University, in connection with his research on this subject.

In preparation for new exhibits for the Museum of History and Technology, Dr. Vladimir Clain-Stefanelli, acting curator of numismatics, journeyed to New York, Omaha, and Chicago to discuss numismatic problems with various specialists and to examine laboratory and exhibit techniques being used by different institutions. Mrs. Elvira Clain-Stefanelli, associate curator of numismatics, has carried on her bibliographical research on Greek metrology.

Mendel L. Peterson, head curator of Armed Forces history, spent the first half of July in Havana, Cuba, and Port Royal, Jamaica. In Havana he examined several Spanish bronze cannons in Cabana Fortress in connection with his study of the marking and decoration of early artillery. In Jamaica he joined the underwater explorations operating from the *Sea Diver II*. United States Navy divers had been working there for some weeks, devoting most of their time to removing silt and coral overburden from the site. The material recovered led to a probable conclusion that this might have been the site of a cookhouse of the type known to have been used in Port Royal. On a subsequent trip to Jamaica, between July 27 and August 11, Mr. Peterson rejoined the expedition, which by that time had begun to recover a large number of objects from the site behind Fort James. It is believed that Port Royal is the richest 17th-century site in the Western Hemisphere. Several years of hard digging will be required to exploit it completely. The research sponsored by Edwin A. Link and the National Geographic Society in this particular area, in which

Mr. Peterson has participated, is certain to cast valuable light on the Colonial period of Jamaica.

Edgar M. Howell, acting curator of military history, visited Sackets Harbor, N.Y., September 13-18, to explore the site of two War of 1812 forts. The excavations produced results far exceeding expectations. Mr. Howell continued the preparation of an article on the career of Harvey Dunn, official combat artist of World War I, and a catalog of his war paintings. Early in December he visited New York and vicinity to interview members of the Dunn family and several of the artist's contemporaries.

Philip K. Lundeborg, associate curator of naval history, made a tour of maritime and naval museums on the northeast coast of the United States, September 21-October 4, and obtained much information that will be of use in preparing the new exhibits in the Museum of History and Technology of the Smithsonian.

EXHIBITIONS

Modernization of several exhibition halls was continued in 1960. Two completely renovated halls illustrating "The World of Mammals" were opened to the public on November 23, 1959. Biological principles, such as how mammals vary geographically, how they adapt to different climates and environment, the various structural adaptations for locomotion, how they obtain their food and defend themselves, are illustrated. Selected groupings of kinds of mammals, such as cats, dogs, bears, pigs, and primates, are displayed separately. Habitat groups show, among others, African buffalo, square-lipped rhinoceroses, lions, zebras, armadillos, proboscis monkeys, and orangutans in natural surroundings. Many of the large African mammals in these halls were collected by President Theodore Roosevelt during his African expedition of 1909-10, sponsored by the Smithsonian Institution. These exhibits were planned by Dr. Henry W. Setzer, associate curator of mammals. Architectural design was by Thomas Baker, who also supervised the preparation and installation of the exhibits. Robert C. Hogue painted the backgrounds of the habitat groups, and Watson Perrygo supervised the taxidermy work and preparation of accessories. The mural was painted by Art Smith.

Planning for "Oceanic Life," which will occupy the large west main hall, advanced during the year, and progress was made on the construction of a replica of a 92-foot blue whale, which will represent the largest living form of animal life. Chris Karras designed the layout of this hall. The contract for the construction of the display fixtures was awarded in June 1960.

On June 30, 1960, the first comprehensive review of fossil fishes and amphibians in the U.S. National Museum of the Smithsonian Institu-

tion was presented to the public. The history and development of these geologically old back-boned animals are traced through millions of years. Transition from life in the water to life on land and the development of jaws are illustrated by diagrams and models. A 14-foot skeleton of the predatory Cretaceous fish *Xiphactinus*, which had swallowed another sizable fish, the dermal-armored giant Devonian joint-necked fish *Dinichthys*, a series of fishes which had inhabited the seas covering Germany during the Jurassic period, and a rock slab with the crowded skulls and bones of the amphibian *Buettneria* which had been trapped in an evaporating Triassic swamp within the boundaries of the present state of New Mexico are displayed in this hall. This exhibit hall was supervised by Dr. David H. Dunkle, associate curator of vertebrate paleontology, and the exhibits design was coordinated by Gorman Bond.

The most colorful habitat groups for the hall of invertebrate paleontology and paleobotany were completed by George Marchand of Ann Arbor, Mich. A giant cephalopod shell, *Parapuzosia*, which was received in many pieces, was restored for a display unit. Scripts for the paleobotanical displays in this hall were prepared by Dr. Erling Dorf of Princeton University. Dr. Gustav A. Cooper, head curator of geology, was responsible for the preparation of the scripts for the remainder of this hall.

Construction of the display units in the hall for the fossil mammals illustrating the "Age of Mammals" was completed and installation commenced. The large fossil mammal skeletons were in place by the end of the year. This hall was designed by Ann Karras in accordance with the script furnished by Dr. C. Lewis Gazin, curator of vertebrate paleontology. Included among the mammals added to the previous exhibit series are skeletons of two horses, *Orohippus* and *Parahippus*, the Oligocene camel *Poebrotherium*, a composite restoration of the Eocene primate *Smilodectes*, and a large primitive rodent, *Ischyrotomos*.

Preparation of specimens for the dinosaur display in the large east main hall was begun near the end of the year. Among these were the skeleton of the Triassic reptile *Trilophosaurus*, remounting the skeleton of the Permian sail lizard *Dimetrodon* and restoring the elongated tail, and restoration of a phytosaur skull from the Triassic rocks of west Texas. Tentative layouts for modernization of the dinosaur hall were developed by Dr. Nicholas Hotton III, associate curator, and exhibits designer Ann Karras.

Preparation of exhibits for the first of two modernized halls of North American archeology was initiated and 17 cases were installed. Among these were topical exhibits on aboriginal North American uses

of tobacco, agriculture and food crops, methods of shaping stone, and historic metal trade goods, as well as interpretations of prehistoric Indian cultures of Alaska, California, and the southwestern United States. The exhibits were designed by Terrell Bridges. Contract construction in the second of two halls of North American archeology was completed in June 1960. Dr. Waldo R. Wedel, curator of archeology, is responsible for the scientific planning of all exhibits in both of these halls.

Curator of ethnology Saul H. Riesenbergr and Associate Curator Eugene I. Knez cooperated with Dorothy Guthrie of the exhibits staff in the development of the architectural layout for the "People of the Pacific" exhibit, which will interpret the material culture of Oceania and southeast Asia. Associate Curators Knez and Gordon D. Gibson also consulted with Mrs. Guthrie in developing a tentative layout of exhibits in an adjoining hall which will be devoted to African and eastern and central Asiatic peoples.

Script for the hall of physics, astronomy, and mathematics was completed by Dr. Robert P. Multhaupt, head curator of science and technology, with the assistance of Consultants Peter Diamadopoulos and Julian H. Bigelow. The unit designs were developed by Benjamin W. Lawless. In August 1959 one of the exhibits for this hall, a full-scale replica of the shop and tools of Henry Fitz, this country's first commercial telescope-maker, was installed in the Arts and Industries Building. Special exhibitions presented by the division of physical sciences during the past year were the first cash register, a gift of the National Cash Register Co., the development of the pyrometer (commemorating the inventions of Edward Brown), a loan display of machinery used in compiling the United States census, an exhibit of American surveying instruments, and a series of astrolabes received from the International Business Machines Corporation.

Curator Eugene S. Ferguson supervised the trial erection of a pre-Civil War machine shop and the restoration of machine tools which will be shown in this shop in the Museum of History and Technology. Associate Curator Edwin A. Battison supervised the erection of a clockmaker's shop which will be a featured exhibit in the hall of light machinery.

Curator Howard I. Chapelle, with the assistance of William Geoghegan, drafted drawings and specifications for the construction of 18 models of historic ship types not represented in the Museum's collections, and continued to supervise the repair and restoration of models in the watercraft collection.

The major portion of the hall of electricity script has been completed by Acting Curator W. James King, Jr., aided by consultants

Robert A. Chipman and Guenter Schwarz. A diorama depicting the broadcast of a program from the studio of pioneer radio station KDKA in Pittsburgh was also completed during the year.

Throughout the year attention was devoted to the development of exhibits of medical and pharmaceutical history which were designed by Ronald Elbert and Fred Craig from specifications furnished by Dr. John Blake and Dr. Sami Hamarneh, curator and associate curator, respectively, of medical sciences.

On February 18, 1960, the new farm machinery hall in the southeast court of the Arts and Industries Building was formally opened. The exhibits illustrate the progressive mechanization of farm work since the early part of the 19th century. Actual machines supplemented by accurate models record the development of these labor-saving devices. Associate Curator Edward C. Kendall was responsible for the planning of this hall and the exhibits were designed by Ronald Elbert.

On December 9, 1959, the section of the textile hall gallery, tracing the history of the development of the sewing machine, was opened to the public. Seven cases show the first United States patents, the development of a practical machine, commercial treadle and hand machines of the 1850's to 1870's, unusual sewing-machine patents of the period, and early sewing-machine attachments for special purposes. A section of this gallery was opened on May 17, 1960, for the display of printing and dyeing techniques from the early painted-cotton fabrics of India through the tie-dyeing, batik, block printing, copperplate printing, roller printing, stenciling, and silk-screen printing.

Theodore A. Randall, professor of ceramics of the New York State University, served as consultant to Acting Curator Paul V. Gardner in planning the hall of ceramics and glass. The Seventh International Exhibition of Ceramic Art was held from August 21 to September 23, 1959, in the foyer of the Natural History building. Foreign ceramics selected and lent by the embassies of the 19 countries represented supplemented ceramics made by American artists of national or international reputation, and pieces exhibited by local artists.

In May 1960 production was completed on the panel exhibits for the second of two large sections of the hall of graphic arts illustrating the history and development of photochemical printing. These exhibits, designed by Harry Hart from scripts written by Assistant Curator Fuller O. Griffith, 3d, will be stored until the Museum of History and Technology building is completed.

Installation of exhibits in the petroleum hall of the Arts and Industries Building was nearing completion at the end of the year.

Scripts for this hall were prepared by Dr. Philip W. Bishop, head curator of arts and manufactures. Associate Curator Charles O. Houston assumed responsibility for the hall of coal. John D. Morrow, formerly president of the Pittsburgh Coal Co. and the Joy Manufacturing Co., is serving as consultant. The planning of the hall of iron and steel continued with the help of consultant Lowell L. Henkel of the Industrial College of the Armed Forces. Dr. Clyde L. Cowan and William C. Cleveland continued in their consultative capacities in nuclear energy and general manufacturing, respectively.

Dr. Anthony N. B. Garvan, head curator of civil history, assisted by Peter C. Welsh, associate curator, and Arlene Krimgold, junior curator, continued the planning for the series of halls which will interpret the growth of the United States. Dr. Wilcomb E. Washburn, curator of political history, with the assistance of Robert Widder, exhibits designer, completed the design for the units of this division. Production of exhibits for the hall of American costume, which was planned by Assistant Curator Anne W. Murray and designed by Judith Borgogni and Virginia Kneitel, was well advanced at the close of the year. Repair and reconditioning of period interiors for the George Washington drawingroom and bedroom were in progress.

On January 3, 1960, a special showing of women's-rights material was prepared for the delegates to the national convention of the National Woman's Party, held in Washington, D.C. During June 1960 a colorful display entitled "America Votes" was presented in the west hall of the Arts and Industries Building. This featured an outstanding collection of banners, tokens, lanterns, and other paraphernalia relating to national political campaigns presented by Ralph E. Becker, and political caricatures and cartoons from the Harry T. Peters collection of American lithography.

A special exhibition of Spanish-colonial silver, principally from Ecuador, was installed in the lobby of the Natural History Building. The silver was collected early in this century by Daniel C. Stapleton and lent by his daughter, Mrs. George W. Renchard of Washington.

In May 1960 two special exhibitions were placed on display in the coin hall by the division of numismatics. Louis Eliasberg of Baltimore lent his entire collection of United States coins, including the specially designed exhibit cases and featuring an outstanding series of Latin American coins and foreign gold, as well as primitive media of exchange. A selection from the Willis H. du Pont gift of Russian coins and medals, formerly owned by the Grand Duke George Mikhailovich of Russia, was displayed in another exhibition illustrating the life and military exploits of Peter the Great.

A number of special exhibitions were shown by the division of

philately during the year, including one of patriotic covers commemorating the approaching Civil War Centennial observances and another featuring the "Liberty for All" theme used in New York for the National Postage Stamp Show.

Considerable improvement in existing exhibits was made by Head Curator Mendel L. Peterson and Acting Curator Edgar M. Howell by clearing the area in front of the Star Spangled Banner and installing Naval and Marine Corps uniforms on the west gallery. Models of the dirigible *Akron*, the aircraft carrier *Shangri-La*, and the armored cruiser *Pennsylvania* were installed in the hall of naval history. From November 20 through December 31, 1959, a special exhibition of the recently acquired and unique W. Stokes Kirk collection of United States military insignia and accouterments was held in the rotunda of the Arts and Industries Building. During January and February 1960 the division of naval history presented in the rotunda of the Arts and Industries Building the "Evolution of U.S. Naval Aviation," which included carrier and aircraft models, selected combat paintings, photographs and significant objects ranging from Eugen Ely's aircraft propeller to a group of current air-to-air missiles.

Under the chairmanship of Dr. Herbert Friedmann, head curator of zoology, the committee coordinating and supervising the modernization of exhibits in the Natural History Building made a critical review of this program. The exhibits program of the Museum of History and Technology, being coordinated by John C. Ewers, assistant director, is concerned primarily with the development of exhibits for the new building. In fields represented by limited museum collections, the assembling of specimens has been an essential prelude to the completion of exhibit plans. John E. Anglim continued in charge of exhibition-hall design and the preparation of exhibits for the entire museum. Benjamin W. Lawless, with the assistance of Robert Widder in design, Bela S. Bory in production, and Robert Klinger in the model shop, supervised the exhibits work for the Museum of History and Technology. Rolland O. Hower, assisted by Thomas Baker and Peter DeAnna, supervised the renovation of the exhibition halls in the Museum of Natural History. Continued assistance in the design of renovated halls in existing buildings was given by Richard S. Johnson, design branch chief, and John H. Morrissey, architectural branch chief of the architectural and structural division of the Public Buildings Service, General Services Administration, and Luther Flouton, Henry R. Kerr, and Charles J. Nora, design architects of that agency. As lighting consultant, Carroll Lusk, museum lighting specialist of Syracuse, N.Y., provided the needed assistance to designers of exhibition halls for the Museum of History and Technology.

DOCENT SERVICE

The Junior League of Washington continued its volunteer program of conducting guided tours in modernized Smithsonian exhibition halls for school children of the Greater Washington area, under the supervision of G. Carroll Lindsay, curator of the Smithsonian Museum Service, working with Mrs. Clark Gearhart, chairman of the Smithsonian Volunteer Docent Committee of the Junior League of Washington, and Mrs. Dean Cowie, cochairman. At the conclusion of the tour season, Mrs. Gearhart was succeeded as chairman by her cochairman, Mrs. Cowie. Mrs. E. Tillman Stirling will serve as cochairman of the Docent Committee for the forthcoming year.

During the 1959-60 season, tours were conducted as before in the Halls of Power, Indians and the Eskimo, and Everyday Life in Early America. In addition, two more modernized exhibits were included—the Hall of Gems and Minerals and the Hall of Textiles.

During the 6-month season from October 1959 to May 1960, 525 tours were conducted, in which 15,658 children participated, representing an increase of 3,662 over the previous year.

For the first time tours were made available to junior high school science students. These included, for this group as well as for elementary school children, the Hall of Gems and Minerals and the Hall of Power.

In addition to Mrs. Gearhart and Mrs. Cowie, the members of the Docent Committee were: Mrs. George Armstrong, Mrs. Harrison Brand III, Mrs. Walter A. Edwards, Mrs. William R. Ford, Mrs. George Gerber, Mrs. William Graves, Mrs. Frederick Irving, Mrs. Edward Lamont, Mrs. Robert Larsen, Mrs. Ralph W. Lee III, Mrs. John T. Malone, Mrs. William Minshall, Jr., Mrs. Minot Mulligan, Mrs. George Pendleton, Mrs. James T. Rasbury, Mrs. Robert Rogers, Mrs. John Schoenfeld, Mrs. W. James Sears, Mrs. John Simmons, Mrs. William D. Sloan, Mrs. James H. Stallings, Mrs. G. G. Thomas, Mrs. E. Tillman Stirling, Mrs. David Toll, Mrs. Richard Wallis, and Mrs. Marc A. White.

BUILDINGS AND EQUIPMENT

In the act of May 13, 1960 (P. L. 86-455) Congress appropriated funds for the construction of an east wing and the air-conditioning of the existing Natural History Building of the Smithsonian. The added space will provide laboratories and workrooms for the scientific staff, more adequate storage space, and the desired climatic control for the preservation of the national collections of anthropology, the natural sciences, and art. Improved facilities for the convenience of the visiting public will also be afforded by this construction. Mills,

Petticord & Mills, of Washington, D.C., are the architects, and the contract for construction will be supervised by the General Services Administration.

The principal contracts for the construction of the Museum of History and Technology Building, were awarded September 16, 1959, and work actually commenced October 5. The contracts were awarded to the Norair Engineering Corporation, Washington, D.C., for construction of the building. The elevators and escalators will be installed by the Otis Elevator Co. Within the plan of the building's structure, which was carefully reviewed and adopted by the Joint Congressional Committee on Construction and subsequently approved by the Commission of Fine Arts, the Smithsonian Institution's staff has developed designs for exhibits for approximately 38 major areas of historical and technological displays. Workrooms for the curatorial staff will be located adjacent to the storage areas for the reserve and study collections of cataloged objects, which provide basic data for interested visitors, students, and professional workers. Laboratories for the preservation and scientific study of materials of historical significance, and shops for exhibit construction and maintenance are included in the plans. The design architects, McKim, Mead & White, advised the Smithsonian Institution during the year on details of construction.

Modern-type seating was installed in the auditorium of the Natural History Building to provide more effective use of this hall. Improvement in the aisle lighting in the auditorium also was accomplished, with visitors' safety in mind.

Two metal buildings erected in the west court of the Natural History Building have provided working space for the exhibits staff as well as production facilities. Recent improvements include the construction of an extension on the west side of one building for housing the taxidermy section and a covered storage area along the east side of the other building to furnish protection to the Northwest Indian wooden boats stored by the division of ethnology. Remodeling of the exhibits laboratory includes a partial second-floor level, design office, general office, two dark rooms, paint spray room, sanding room, paint storage room, restoration room, enlarged cabinet shop, and general work area. Lighting installations, installation of ventilating equipment, plumbing and heating revisions, electric service modifications, and related work are also provided.

Increasing needs for working space made the proper utilization of available areas imperative. Useful space was gained by the construction of second-floor levels in five rooms on the ground floor of the Natural History building.

All marble surfaces of the north entrance lobby and vestibule of the Natural History Building were renovated, the bronze surfaces

scoured and coated to retard deterioration, the exterior grille doors removed, the center revolving door removed and the original bronze doors rehung, and the ceilings and walls repainted.

A public rest area with shade trees, shrubs, sidewalks, curbs, fences and permanent-type benches has been constructed along the north side of the Arts and Industries Building.

CHANGES IN ORGANIZATION AND STAFF

Effective May 31, 1960, the division of woods was established in the department of botany, Museum of Natural History. Dr. William L. Stern was appointed curator of this division on June 1, 1960. Concurrently the division of woods in the department of science and technology was abolished.

Dr. Gus W. Van Beek was appointed associate curator of the division of archeology, department of anthropology, on July 1, 1959.

Dr. Richard Cifelli accepted an appointment as associate curator in the division of invertebrate paleontology and paleobotany on July 1, 1959. Another vacancy in this division was filled by the appointment of Erle G. Kauffman as assistant curator on June 15, 1960.

Carl H. Scheele was appointed, effective September 29, 1959, assistant curator of philately, and Dr. Sami K. Hamarneh, associate curator of medical sciences on September 24, 1959.

In the division of cultural history, John N. Pearce was appointed assistant curator on October 5, 1959. The vacancy in the division of industrial cooperation was filled on December 23, 1959, by the appointment of Dr. Charles O. Houston.

On February 1, 1960, Dr. John J. Wurdack reported for duty as associate curator of the division of phanerogams.

A. J. Wedderburn, Jr., associate curator of graphic arts, resigned on March 15, 1960, to accept other employment.

Dr. Paul Bartsch, who had retired on April 30, 1946, after serving 50 years on the staff of the United States National Museum, and as an honorary associate in the division of mollusks since that date, died at Lebanon, Va., on April 24, 1960.

Dr. J. B. Knight, research associate in invertebrate paleontology since January 1, 1955, and from January 1, 1945, to December 31, 1954, associate curator in that division, died at Sarasota, Fla., on March 21, 1960.

Respectfully submitted.

REMINGTON KELLOGG, *Director.*

DR. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

Report on the Bureau of American Ethnology

SIR: I have the honor to submit the following report on the field researches, office work, and other operations of the Bureau of American Ethnology during the fiscal year ended June 30, 1960, conducted in accordance with the act of Congress of April 10, 1928, as amended August 22, 1949, which directs the Bureau "to continue independently or in cooperation anthropological researches among the American Indians and the natives of lands under the jurisdiction or protection of the United States and the excavation and preservation of archeologic remains."

SYSTEMATIC RESEARCHES

Dr. Frank H. H. Roberts, Jr., Director of the Bureau, devoted part of the year to general supervision of the activities of the Bureau and the River Basin Surveys. In July he inspected the work of excavating parties operating in the Pomona Reservoir area in Kansas, the Big Bend and Oahe Reservoir areas in South Dakota, and a portion of the Oahe Basin in North Dakota. Three of the parties were from co-operating agencies and three represented the River Basin Surveys. In addition, he visited two excavations that were not a part of the salvage program, one conducted by a University of Nebraska field party and the other by a group from the State Historical Society of Nebraska. Dr. Roberts was accompanied by Carroll Burroughs from the Branch of Archeology of the Washington office of the National Park Service and Dr. Robert L. Stephenson, Chief of the Missouri Basin Project of the River Basin Surveys. While at Pierre, S. Dak., they participated in an informal conference attended by leaders of all the parties working in the Plains during the summer, many of their student helpers, and representatives from various universities and museums in the area. Virtually every phase of Missouri Basin archeology was discussed.

In November Dr. Roberts went to Lincoln, Nebr., where he reviewed the operations of the field headquarters and laboratory of the River Basin Surveys and took part in the sessions of the Plains Archeological Conference at the University of Nebraska. At Omaha he met with representatives of the Corps of Engineers and the Region Two Office

of the National Park Service to consider various problems pertaining to salvage operations in the Missouri Basin.

During late December and early January Dr. Roberts represented the Bureau at the meetings of the American Anthropological Association in Mexico City. He also visited various museums and archeological sites in the surrounding area. Late in January after his return to Washington he participated in the meetings of the Committee for the Recovery of Archeological Remains held at the Department of the Interior. He presented a summary of the results of the activities of the River Basin Surveys during the preceding year and joined in the discussions pertaining to future plans for the Inter-Agency Archeological Salvage Program.

In April Dr. Roberts went to Lincoln to inspect the operations of the Missouri Basin project office and met with representatives of Region Two of the National Park Service to consider the fiscal situation and fieldwork to be carried on during the 1960 summer season. Dr. Roberts assisted in the preparation of budgets and plans for the various River Basin Surveys parties which were to be leaving Lincoln early in June.

At the request of the National Park Service, Dr. Roberts was authorized to serve as a member of an advisory group for the Wetherill Mesa excavations at Mesa Verde National Park. He went to Mesa Verde late in May and with other members of the group inspected the work under way at two large cliff ruins and in the project laboratory. The group spent one day discussing various problems pertaining to the project and made a number of recommendations with respect to the continuance of the investigations.

Dr. Roberts did the technical editing of a series of four reports on archeological excavations in three reservoir areas. They will appear as River Basin Surveys Papers Nos. 21-24 in Bulletin 179 of the Bureau of American Ethnology.

Dr. Henry B. Collins, anthropologist, continued his Eskimo studies and other Arctic activities. He prepared an article on the native peoples of the Arctic for a forthcoming edition of the *Encyclopaedia Britannica*, and his paper on Eskimo art appeared in the first issue of Dartmouth College's new journal devoted to Polar research. In another paper, published in *Current Anthropology*, he discussed recent archeological discoveries in Alaska and Siberia and assessed the roles of local culture growth, diffusion, trade, population movements, tradition, and geographical patterning as causative factors involved in the development and continuity of prehistoric Eskimo culture in the Bering Strait area.

Dr. Collins was elected to the Board of Governors of the Arctic Institute of North America for a 3-year term. He continued to serve

as a member of two Arctic Institute committees: (1) the Publications Committee, which is responsible for preparation of the Institute's quarterly journal *Arctic* and its two series, *Technical Papers* and *Special Publications*, and (2) the Research Committee, which plans the Institute's research program by passing upon grant applications, acting as a scientific advisory group for military agencies engaged in conduct of basic research in the Arctic and Antarctic, and planning programs of Polar research which the Institute administers for Government agencies and other organizations.

He also continued to serve as chairman of the directing committee of the *Arctic Bibliography*, a comprehensive work prepared by the Arctic Institute of North America for the Department of Defense. The purpose of the bibliography is to provide a key to scientific publications in the principal libraries of the United States and Canada relating to the Arctic and sub-Arctic areas and to low-temperature conditions, and to assemble and systematize this material so that it may be readily available to scientists and others concerned with problems of northern research and development. In continuation of this program, Volume 8 of *Arctic Bibliography* (1,281 pages) was issued by the Government Printing Office in September 1959. It summarizes and indexes the contents of 5,622 publications in all fields of science. Volume 9, containing abstracts of 7,192 publications, is in press, and work is in progress on Volume 10. Covering the entire range of scientific literature in all languages on the Arctic and subarctic regions of the world, the *Arctic Bibliography* to date has abstracted and indexed the contents of 56,278 publications relating to these areas and to low-temperature conditions.

In July 1959 Dr. Collins submitted a proposal to the National Science Foundation for the Arctic Institute of North America to translate Russian anthropological publications relating to northern Eurasia. Much of the Soviet and earlier Russian anthropological literature, particularly that on the archeology, ethnology, and physical anthropology of Siberia, has a direct bearing on problems of American anthropology. However, this Russian literature is not available to the great majority of English-speaking anthropologists. English translations of selected articles and monographs from Russian journals and series would begin to meet this long-felt need. In March 1960 the National Science Foundation awarded a grant to the Arctic Institute for the translation project and the work began in April, under the direction of Dr. Henry N. Michael of Temple University. An advisory committee, of which Dr. Collins is chairman, selects materials for translation and advises on matters pertaining to the publication and distribution of the translations. The translations will be printed in an inexpensive format, as a special publication series of the Arctic Institute, and offered for sale at modest prices.

With the support of grants from the American Philosophical Society and the National Science Foundation, Dr. Collins left for Europe June 24 to make a comparative study of archeological materials in European museums and to attend the 34th International Congress of Americanists in Vienna and the 6th International Congress of Anthropological and Ethnological Sciences in Paris.

At the beginning of the fiscal year, Dr. William C. Sturtevant, ethnologist, was concluding a period of fieldwork begun in February 1959 among the Seminole Indians in Florida. Returning north, he spent July 8 in and around Charleston, S.C., where he examined several old Southeastern Indian specimens and a portrait of Osceola, the famous Seminole leader, in the Charleston Museum, visited Osceola's grave at nearby Fort Moultrie, and briefly investigated modern Gullah Negro basketmaking near Fort Moultrie.

On his return to Washington, Dr. Sturtevant spent most of his time at work on the materials collected during his extended field trip in Florida. He also prepared a paper on the agriculture of the 16th-century Taino Indians of the West Indies, which he delivered at the 58th Annual Meeting of the American Anthropological Association in Mexico City in December. While in Mexico Dr. Sturtevant visited the impressive Maya archeological site at Palenque and then spent four days observing the lacquer-making industry at Uruapan, Michoacán, and making a small collection illustrating this craft for the National Museum.

In mid-November, Dr. Sturtevant spent two days at Newtown, Cattaraugus Reservation, New York, for the wake and funeral of Solon Jones, who was a leader of the Longhouse religion, a great expert on Seneca ceremonies, a well-known orator in Seneca, and in his younger days a famous lacrosse player. Mr. Jones will be greatly missed by his many Iroquois friends and coreligionists and also by anthropologists familiar with his community.

Dr. Sturtevant attended the 12th Conference on Iroquois Research (Red House, N.Y., in October), the annual meetings of the Association for Asian Studies (New York, in April), and the Society for American Archaeology (New Haven, in May).

Dr. Wallace L. Chafe, linguist, was engaged in fieldwork on the Tonawanda Reservation in New York State during July, August, and early September. He collected material for the completion of a Seneca dictionary and recorded and transcribed several religious texts which are part of the Longhouse ceremonial pattern. This fieldwork was sponsored by the New York State Museum and Science Service in cooperation with the Bureau of American Ethnology.

Dr. Chafe served as chairman of the 12th Conference on Iroquois Research, held at Red House, N.Y., October 16-18.

During the first three weeks of November Dr. Chafe traveled to North Dakota and Oklahoma to acquaint himself with the present number and location of speakers of the Caddoan languages. This language family includes Arikara, Pawnee, Wichita, and Caddo. He obtained estimates of the number of speakers of each language, collected word lists, and made lexicostatistic comparisons. The trip was made under a grant from the American Philosophical Society.

He returned to North Dakota for the first three weeks of June to collect further material on the Arikara language. He obtained phonological, grammatical, and lexical data which will be used in a comparative study of the languages of the Caddoan family.

Dr. Chafe published articles on the Seneca language in *Language* and the *International Journal of American Linguistics*. In March he completed an index of the journal *Language* for the years 1955-59. Under the auspices of the American Philosophical Society, he began work during the spring on a project designed to obtain estimates of the present number of speakers of each of the Indian languages of North America.

RIVER BASIN SURVEYS

The River Basin Surveys continued its participation in the Inter-Agency archeological and paleontological salvage program. Its activities were in areas to be flooded or otherwise destroyed by the construction of large dams. The work was carried on in cooperation with the National Park Service and the Bureau of Reclamation of the Department of the Interior, the Corps of Engineers of the Department of the Army, and a number of State and local institutions. The investigations during the fiscal year 1959-60 were supported by a transfer of \$122,055 from the National Park Service to the Smithsonian Institution. Of that sum, \$98,055 was for use in the Missouri Basin and \$24,000 for investigations along the Chattahoochee River in Alabama and Georgia. On July 1, 1959, the Missouri Basin Project had a carryover of \$10,764, and that, with the new appropriation, provided a total of \$108,819 for the program in the Missouri Basin. The grand total of funds available for the River Basin Surveys for 1959-60 was \$132,819.

Activities in the field throughout the year were mainly concerned with excavations, although some limited surveys were carried on and one party made a series of studies of skeletal material in museums and laboratories throughout the Missouri Basin. Because of a reduction in funds, fieldwork was more limited than in the previous year. On July 1, 1959, there were three excavating parties working in the Missouri Basin in South Dakota, and the mobile group was operating in Nebraska. One of the parties in South Dakota was digging sites in the Big Bend Reservoir area and the other two were working in

the Oahe Reservoir area. The excavating parties completed their work and returned to the headquarters at Lincoln, Nebr., in August, while the mobile party finished its season on August 21, after having visited 22 institutions and 11 field camps in six Missouri Basin and three adjacent States.

In December one small party made a brief trip to the Lewis and Clark Lake above the Gavins Point Dam to examine a site which was being destroyed by wave action. The same party also visited a mound group near Mitchell, S. Dak., where unauthorized digging had been reported. The cooperation of the owner was obtained to prevent further destruction of the site which is an exceptional one for that area. From Mitchell the party proceeded to the Big Bend Dam site and made an inspection of the construction activities then under way. A second party returned to the Lewis and Clark Lake in February and spent eight days salvaging materials from the site which had been examined in December. In addition to a member of the River Basin Surveys staff there was a representative from the Laboratory of Anthropology of the University of Nebraska. These men were assisted by the area engineer, the reservoir naturalist, and the reservoir manager. The cooperative effort produced materials which identified the site as being attributable to the Woodland cultures. Activities along the Chattahoochee River in Alabama-Georgia were resumed in January when a survey-testing party began operations in the Walter F. George Reservoir area which continued until mid-June when work was stopped and the head of the party returned to Lincoln, Nebr. Early in June one party began excavations in the Big Bend Reservoir area near the dam axis and another started digging at a mound site near the North Dakota-South Dakota boundary in the Oahe Reservoir area. A third party began studies the latter part of the month at the site of historic Fort Sully north of Pierre in the Oahe Reservoir Basin. All three were continuing their investigations at the end of the fiscal year.

As of June 30, 1960, the River Basin Surveys had carried on reconnaissance work or excavations in 255 reservoir basins located in 29 States. In addition, four canal areas and two lock projects had also been investigated. The sites located during the years between 1946, when the program started, and the close of the fiscal year total 4,948, and of that number 1,154 were recommended for excavation or limited testing. Because of the large number of sites and the lack of sufficient time and funds for the work, complete excavation has not been possible in any but a few exceptionally small ones. For that reason, when the term "excavation" is used, it implies digging only as much of a site as is deemed necessary to obtain a good sample of the materials and information to be found there.

Preliminary appraisal reports have been issued for most of the reservoir areas which were surveyed. In a few cases no archeological manifestations were noted and no general report was distributed. During the last fiscal year preliminary appraisal reports for the Oliver Dam, the Walter F. George Dam and Lock project, and the Columbia Dam and Lock project on the Chattahoochee River were mimeographed and distributed. Since the beginning of the salvage program 188 such reports have been issued. The discrepancy between the number of reservoirs surveyed and that of the reports issued is due to the fact that in several cases a number of projects located within a single basin or sub-basin were covered in one report.

By June 30, 1960, 487 sites in 54 reservoir areas located in 19 different States had been either tested or dug sufficiently to provide good information about them. The sites investigated range in age from those representing hunting and gathering cultures of about 10,000 years ago to early historic Indian village locations and the remains of frontier trading and Army posts of European origin. The results obtained from some of the excavations have been published in the Smithsonian Institution Miscellaneous Collections, in Bulletins of the Bureau of American Ethnology, and in various scientific journals and historical publications. During the year River Basin Surveys Papers Nos. 21-24, comprising Bulletin 179 of the Bureau of American Ethnology, were sent to the printer. The papers consist of a report on excavations in the Texarkana Reservoir Basin on the Sulphur River in east Texas, the Coralville Reservoir area on the Des Moines River in Iowa, and two detailed accounts about work in various sites in the McNary Reservoir area on the Columbia River. The Texarkana report was written by Edward B. Jelks. The Coralville paper was prepared by Warren W. Caldwell and the McNary Reservoir papers were the work of Joel L. Shiner and Douglas Osborne. The latter two round out and complete the data which were contained in Osborne's River Basin Surveys Paper No. 8, Bulletin 165, "Excavations in the McNary Reservoir Basin near Umatilla, Oregon." At the end of the year the editors were working on Carl F. Miller's manuscript which gives in detail the results of his excavations at the John H. Kerr Reservoir basin in the Roanoke River, Virginia-North Carolina.

On June 30, 1960, the distribution of reservoir projects that had been surveyed for archeological remains was as follows: Alabama, 4; Arkansas, 1; California, 20; Colorado, 24; Georgia, 8; Idaho, 11; Illinois, 2; Iowa, 3; Kansas, 10; Kentucky, 2; Louisiana, 2; Minnesota, 1; Mississippi, 1; Montana, 15; Nebraska, 28; New Mexico, 1; North Dakota, 13; Ohio, 2; Oklahoma, 7; Oregon, 27; Pennsylvania, 2; South Carolina, 1; South Dakota, 10; Tennessee, 4; Texas, 19; Virginia, 2; Washington, 11; West Virginia, 3; Wyoming, 22.

Excavations had been made or were under way in reservoir areas in Arkansas, 1; California, 5; Colorado, 1; Iowa, 1; Georgia, 7; Kansas, 5; Montana, 1; Nebraska, 1; New Mexico, 1; North Dakota, 4; Oklahoma, 2; Oregon, 4; South Carolina, 2; South Dakota, 4; Texas, 7; Virginia, 1; Washington, 4; West Virginia, 1; Wyoming, 2. The preceding figures include only the work of River Basin Surveys or that where there was direct cooperation between the Surveys and local institutions. The work done by State and local institutions under agreements with the National Park Service has not been included because complete information about them is not available in the River Basin Surveys office.

The National Park Service, the Bureau of Reclamation, the Corps of Engineers and other Army personnel, and various State and local institutions contributed helpful cooperation throughout the year. Transportation and guides were provided by the Corps of Engineers for the reconnaissance in one of the reservoir areas, and invaluable help was received through the commanding officer at Fort Benning in Georgia who assigned certain Army personnel to assist in some of the activities in the portion of the Walter F. George Reservoir Basin which lies in the Fort Benning Reservation. In addition, the Army Air Command at Lawson Field furnished a helicopter so that aerial photographs could be made of major archeological sites and current excavations, as well as the progress in construction of both the Columbia Dam and Lock and the Walter F. George Dam and Lock. In the Missouri Basin the project engineers for the Oahe Reservoir provided storage space for equipment and also space for temporary living accommodations. Mechanical equipment was lent in several instances by the construction agency, which accelerated both the stripping of the top soil from sites and the back-filling of trenches and test pits. The field personnel of all of the cooperating agencies assisted the party leaders from the River Basin Surveys in numerous ways and the relationship was excellent in all areas. Both in Washington and in the field the National Park Service continued to serve as the liaison between the various agencies. The Park Service also prepared the estimates and justifications for the funds needed to carry on the salvage program. Along the Chattahoochee River the Georgia Historical Commission, the University of Georgia, and various local clubs and groups of citizens in both Alabama and Georgia assisted the leader of the River Basin Surveys party in many ways.

General supervision of the program was carried on from the main office in Washington, while the activities in the Missouri Basin continued to operate from the field headquarters and laboratory at Lincoln, Nebr. The latter also provided equipment and office assistance for the Chattahoochee River project. The Lincoln laboratory

processed the materials collected by excavating parties in the Missouri Basin and also handled those from the Chattahoochee Basin.

Washington office.—The main headquarters of the River Basin Surveys at the Bureau of American Ethnology continued throughout the year under the direction of Dr. Frank H. H. Roberts, Jr. Carl F. Miller, archeologist, was based at that office and from time to time assisted the Director in some of the general administrative problems. Harold A. Huscher, archeologist, worked under the general supervision of the Washington office but because of lack of space and laboratory facilities continued to work at the field headquarters in Lincoln, Nebr.

At the beginning of the fiscal year Mr. Miller was occupied with the technical report on excavations which he previously conducted at the Hosterman Site in the Oahe Reservoir basin in South Dakota. In September he attended a conference on eastern archeology held at Ligonier, Pa., under the auspices of the Carnegie Museum of Pittsburgh and composed of a group of invited guests. The problems discussed were mainly concerned with the Paleo-Indian, Eastern Archaic, and Woodland cultures. In October Mr. Miller made a survey of the Sutton Reservoir area in West Virginia. In November he attended the Southeastern Archeological Conference held at Macon, Ga. He completed his report on the Hosterman Site in February. During April he made a survey of archeological sites along the Cowpasture River in Bath County, Virginia, investigating a number of small rock mounds and several open sites. During the year Mr. Miller examined and reported on several collections of artifacts which were sent in from various areas in the East and Southeast. He also gave a number of talks before various groups and societies in the Washington area.

At the beginning of the fiscal year Mr. Huscher was in the Lincoln office working on maps, records, and collections from the Oliver Dam and Reservoir, the Columbia Dam and Lock, and the Walter F. George Dam and Lock in the Chattahoochee Basin between Alabama and Georgia. In July he attended a field conference held at Pierre, S. Dak. In November he went to Macon, Ga., and participated in the Southeastern Archeological Conference held there. On his return to Lincoln he attended the Plains Conference which was held at the University of Nebraska. His three appraisal reports on the Chattahoochee projects were completed in October, November, and December. They were processed at the Lincoln office and were distributed from the Washington office in April. In January Mr. Huscher returned to the Alabama-Georgia area where he resumed his field investigations in the Walter F. George Reservoir area. He returned to Lincoln late in June and at the end of the fiscal year was on annual leave.

Alabama-Georgia.—From January 19 to June 13 a series of test excavations was carried on at 10 sites in the area to be flooded by the Walter F. George Dam and Lock project. Six of the sites were in Georgia and four in Alabama. Because the season was unusually wet, work was limited for much of the time to sites in the sandy bottoms. At each location a number of pits 10 feet square were sunk through the deposits to sterile subsoil. At one of the sites in Georgia the main occupation appeared to have been Early Mississippian, although there was a thin surface overlay of the late Creek potsherds. There were some indications that Weeden Island peoples had been there for a time, and in the bottom levels decomposed flints similar to those which occur in abundance on the Macon Plateau were present. The various materials from the site suggest a long period of occupation or several occupations at intervals covering a considerable span of years. At two of the Georgia sites there were large plowed-down mounds with indications of village areas. One of them presumably dates from the Archaic period, and the other, in addition to Archaic materials from levels below the mound, also gave evidence of Weeden Island affiliations. Several of the sites contained Woodland materials, and one of those in Alabama presumably was the location of the Yuchi village mentioned by William Bartram and Benjamin Hawkins in their reports on travels through the Creek country in the 18th century. During the field season collections were made from a total of 48 sites, 26 of which had not been previously investigated. Field lots of specimens, most of which were excavated, numbering 1,680, were added to the previous 1,086 field lots collected in the 1958 and 1959 seasons. This makes a total of 2,766 field lots for the three seasons of investigations along the Chattahoochee.

In addition to the work of the River Basin Surveys parties there were cooperative projects by the University of Georgia, the University of Alabama, and Florida State University. At the end of the fiscal year the University of Georgia was excavating a large platform mound near Stark's Landing in Georgia. The University of Alabama was digging in a village site adjacent to a large mound near Upper Francis Landing in Alabama. The Florida State University party was beginning investigations at the Spanish Fort of Apalachicola and the adjacent aboriginal village near Holy Trinity, Ala.

Missouri River Basin.—The Missouri Basin Project, for the fourteenth consecutive year, continued to operate from the field headquarters and laboratory in Lincoln, Nebr. Dr. Robert L. Stephenson served as chief of the project throughout the year. Activities included surveys, excavations, analysis of materials, and reporting on results. During the summer months efforts were mainly concerned with excavations. Analyses and the preparation of reports received

the major attention during the winter months. The special chronology program, begun two years ago, continued to receive attention throughout the year.

At the beginning of the fiscal year the permanent staff, in addition to the chief, consisted of five archeologists, one administrative assistant, one clerk-stenographer, one part-time file clerk, one clerk-typist, one illustrator, one photographer, and three museum aides. Temporary employees included one cook and six crewmen.

During the summer field season one archeologist and one physical anthropologist were temporarily added to the staff. During July, 11 additional crewmen were employed. The temporary archeologist was terminated on August 23, and the temporary physical anthropologist on August 21. All field crewmen were terminated during the last week of August.

On September 4, one permanent archeologist resigned to return to graduate school, and on May 27 one permanent archeologist resigned to join the staff at the University of Tennessee. On January 2, the clerk-typist resigned, and on February 5, the clerk-stenographer resigned. On February 23, a clerk-stenographer joined the staff but resigned on April 1 and was replaced on May 2. The file clerk was transferred from part time to full time on June 27. The temporary cook was transferred to laboratory assistant on September 1 and to the permanent staff on January 2. During the period from April 2 to June 1, one archeologist was lent to the National Park Service to conduct archeological excavations at Colonial National Historical Park, Yorktown, Va.

At the end of the fiscal year there were three archeologists in addition to the chief, one administrative assistant, one file clerk, one clerk-stenographer, one illustrator, one photographer, three museum aides, and one laboratory assistant on the permanent staff, and 12 crewmen on the temporary staff.

During the year there were nine Smithsonian Institution River Basin Surveys field parties at work within the Missouri Basin. Two were in the Oahe Reservoir area, one in the Big Bend Reservoir area, and one (a mobile party) covered the Missouri Basin area in general during July and August. Two small parties made investigations during December and February in the Gavins Point Reservoir area. Two parties were excavating in the Oahe Reservoir area and one in the Big Bend Reservoir area during June.

Other fieldwork in the Missouri Basin during the year included 10 parties from State institutions operating under cooperative agreements with the National Park Service and in cooperation with the Smithsonian Institution in the Inter-Agency Archeological Salvage Program.

Reduction of funds for fiscal year 1960 necessitated a curtailment of field activities, in comparison with past years, and a shift in the methods of carrying on the salvage program. Despite the accomplishments of previous years in salvaging archeological values from the many reservoir areas in the Missouri Basin, scores of sites still remain to be studied and the reservoirs are rapidly nearing completion. The enforced reduction of activities presented a critical problem. The shift, or readjustment, in methods of fieldwork seemed the only reasonable expedient to accomplish the mission set out for the Salvage Program. This was a shift from major excavation of key sites and sampling of nearby, related sites, to a mere sampling of both key and secondary sites. This change in emphasis will be satisfactory for at least two seasons because of the earlier work in these same areas when full-scale excavations were possible at a number of key sites. There is a framework of information from extensively excavated sites against which the data from the newly sampled sites can be evaluated. There are, however, many major sites, outside the known cultural framework, that promise to provide an abundance of new information if excavated, but little or nothing if only sampled. Another year, these sites must be excavated or lost forever. The sampling approach, in the face of limited field activities, produced worthwhile results in the field seasons of 1959 and 1960. Full-scale excavations of key sites, though, must again be carried on in succeeding years.

At the beginning of the fiscal year, Dr. Warren W. Caldwell and a crew of six were engaged in testing a series of sites in the Big Bend Reservoir area. The specific locality was that of the construction area of the dam along the right bank of the Missouri River in Lyman County, South Dakota, and extending upstream to the area of the old Lower Brulé subagency, a distance of approximately 12 miles. Sampling investigations were made at 19 of the recorded sites in the area and two new sites were located, recorded, and tested. A variety of cultural manifestations is represented.

The first group of these sites is located near the mouth of Good Soldier Creek in the area where the powerhouse and right abutment for the Big Bend dam is to be built. Site 39LM235 had been partially destroyed by landing-ramp construction but was extensively tested in the remaining portions. Site 39LM236 was inundated by extreme high water of the Fort Randall Reservoir and tests made in it in the latter part of the season, after the water had receded, again demonstrated the uselessness of working a site that had been flooded. Sites 39LM237 and 39LM238 were examined with limited test pits. All four sites consisted of stratified concentrations of refuse material partially exposed in the cut bank along the river and creek. Very little artifact

material was recovered this season and the results of the tests proved to be of small diagnostic value. The first three appear to have been sporadically occupied camping places. The fourth, the Good Soldier Creek site (39LM238), previously investigated, is a stratified site of Plains Woodland affiliation overlain by a Mississippian component.

A series of six sites near the mouth of Councilor Creek was investigated. Site 39LM240 was briefly tested and proved to be another sporadically occupied camp site with a few potsherds of the Iona types suggesting occupation in the later ceramic period of circular earth lodges. Site 39LM234 was extensively tested with a series of 10 test pits scattered through the multitude of hummocks and depressions on the surface. Results were disappointing but adequate to demonstrate that it was the location of a village of one of the late periods in the area. Sites 39LM88 and 39LM89, newly located in 1959, and the Tom Rattler site (39LM214) were briefly tested with very little diagnostic material being recovered. The Useful Heart site (39LM6) was extensively tested. There a sterile mantle 3 to 4 feet in depth covered the remains of a village of late circular houses related to the Stanley Focus. A lower level of occupation at a depth of 6.5 feet represented an earlier time level with pottery related to the Over Focus.

The next group of sites upstream (39LM229, 230, 231, and 233) were all briefly tested with negative results and written off as small, sporadically occupied camp sites. A fifth site in this group, the Pretty Head site (39LM232) was not investigated as it was the location of a large village and is scheduled for more extensive excavation than time would allow in the 1959 season. It is the only site in that immediate vicinity where additional work is required. The next group upstream included site 39LM217, where brief testing produced only scattered evidence of sporadic occupation, and four significantly productive sites. The School site (39LM216) was the remains of a large village of circular earth lodges and contained pottery of Iona types. One house quadrant and several test trenches were excavated. The Crazy Bull site (39LM219) was another large village site of circular earth lodges and provided pottery of the Iona, Stanley, and Talking Crow types. Half a house and several test trenches were excavated. Site 39LM220, likewise, had been a village of circular earth lodges and it yielded pottery predominantly of the Iona types. There a half house and several test trenches were excavated. Site 39LM221 was a group of three moderate-size burial mounds. Trenching in them uncovered burial pits, infant burials, and scattered human bones. The artifacts were not abundant but were sufficient to demonstrate a probable relationship of the site to the Truman Mound group (39BF224) excavated by Robert W. Neuman in 1958. Finally a brief investigation

of one feature was made at the Hickey Brothers site (39LM4), excavated by Bernard Golden in 1958. There a probable rectangular house pattern was partially uncovered, but the data from the site still are inadequate for a convincing demonstration of the cultural group to which it belongs.

In all, the Caldwell party examined 21 sites, of which 1 was a burial mound group, 1 was a large village probably of the rectangular house period, 4 were large villages of late circular earth lodges, 1 was a stratified village of rectangular earth lodges overlain by an occupation of later, circular earth lodges, and 14 sites which were sporadically occupied camps producing little diagnostic material. Except for the Pretty Head site (39LM232), all others in this area may now be written off as not requiring further investigation unless something new is uncovered in the course of construction of the Big Bend Dam. The Caldwell party terminated the season's work on August 6, after 9 weeks in the field.

The second River Basin Surveys party in the field at the beginning of the year was a team of physical anthropologists consisting of William M. Bass, III, and two assistants. They were engaged in a survey of human skeletal materials from all the reservoir areas in the Missouri Basin, as well as skeletal materials from other institutions and areas outside reservoirs for the purpose of bringing together data on all the presently extant Indian remains from the Plains area. They visited all the field camps, assisting in the excavation of burials where needed, and went to all the museums and other repositories of archeological materials in the general area. They took anthropometric measurements on the remains of over 2,000 individuals, studying 22 institutional collections and visiting 11 field camps in Oklahoma, Kansas, Missouri, Nebraska, Iowa, Wisconsin, Minnesota, South Dakota, and North Dakota. The analyses of the scores of measurements, both cranial and postcranial, taken on each of the 2,000 individuals, will provide the first broad study of the physical characteristics of the Indians who occupied the prehistoric villages in the various reservoir areas in the Missouri Basin. With the data on the differences between the physical types, the archeologist will be in a much better position to understand the cultural movements of peoples between villages and village areas. This field party was materially assisted, through the kindness of Dr. Wilton K. Krogman, by a grant-in-aid to Bass from the University of Pennsylvania Child Growth and Development Center. The party completed its season on August 21, after 9 weeks in the field.

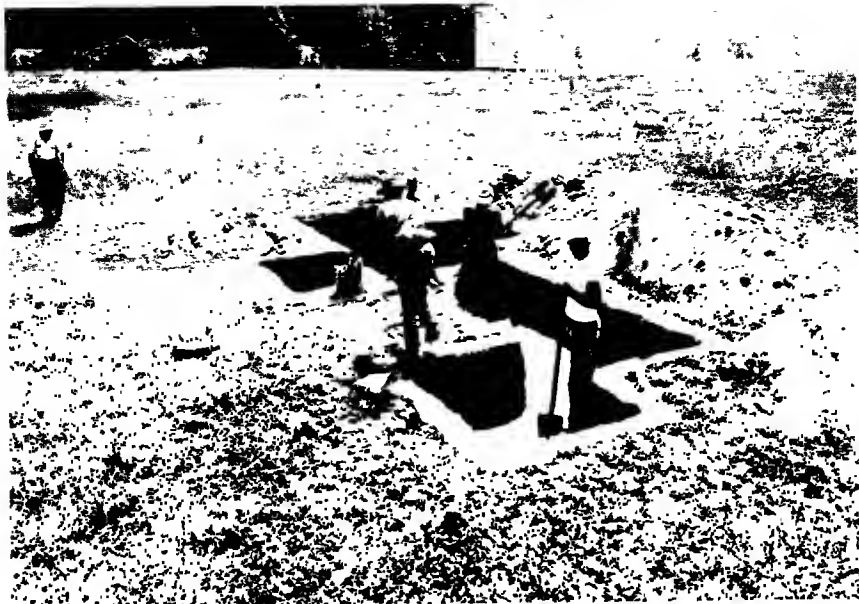
The third River Basin Surveys field party of the 1959 season began work in the Little Bend area of Sully County, South Dakota, in the Oahe Reservoir, on July 2. It consisted of a crew of seven under the

direction of Dr. Charles H. McNutt. This party, like that of Caldwell in the Big Bend Reservoir, spent the season making a series of small-scale test excavations in a large number of sites along a restricted area of the Missouri River. The crew was supplemented in mid-season by 5 additional crewmen, making a total party of 12. Sample excavations were conducted at 18 of the 22 previously recorded sites in the Little Bend. The remaining four sites are of sufficient elevation to remain above water and also appear to be of minor significance. In addition, 11 new sites were located and recorded but only one was of sufficient value to warrant testing and mapping.

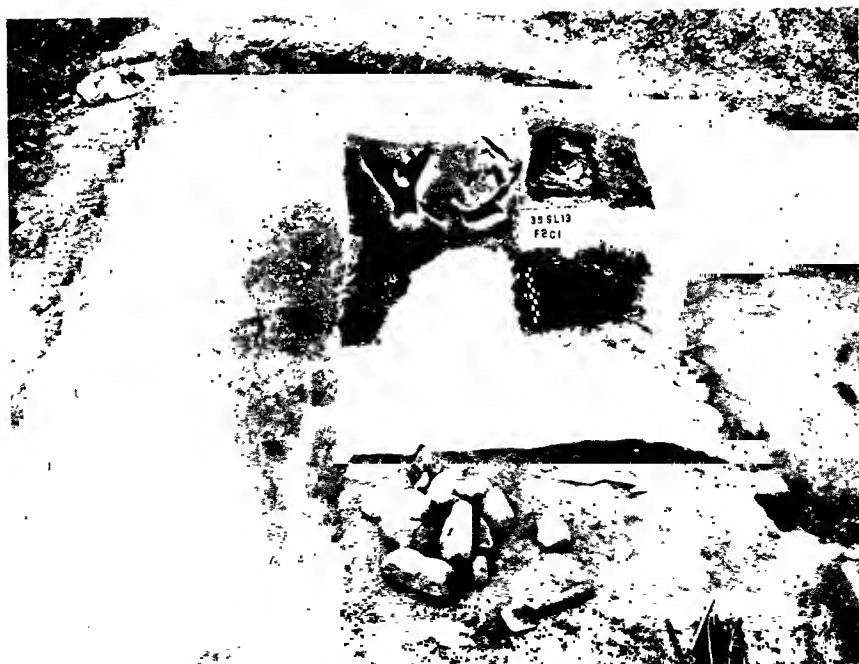
The uniformity of the cultural materials from the Little Bend is rather remarkable. Only two sites (39SL12 and 39SL13) provided any evidence of long-rectangular house villages, and that is only in the form of Thomas Riggs types of pottery. All the other sites had been small to large villages of circular earth lodges providing sherds of only two major classes of pottery, Russell Ware and Stanley Ware. House depressions in all sites are uniformly circular and are usually either ringed, shallow depressions, or unringed deep depressions. Russell Ware pottery occurs characteristically with the former and Stanley Ware pottery with the latter. The consistency of this association is striking. Villages with ringed house depressions and Russell Ware pottery were usually compact and consisted of 1 large (presumably ceremonial) house and from 5 to 10 small (presumably domiciliary) houses. No fortifications were found in association with any of these villages. Villages with unringed, deep house depressions and Stanley Ware pottery were either compact or diffuse and may or may not have had a particularly large (ceremonial) house and a fortification ditch. Some historic material was found in three of the four sites of this type examined. The individual sites are summarized briefly.

Site 39SL12 consists of the remains of a large ceremonial house and at least seven smaller houses located on a low, bench promontory. Three midden heaps and three cache pits were tested and the site was mapped. No defensive ditch could be found. Pottery consisted of both Russell Ware and Thomas Riggs Ware. Site 39SL13 is likewise situated on a low bench promontory and consists of some 40 house depressions, including 2 large ceremonial houses but no defensive ditch was located. There, 3 house depressions were tested, and 1 midden heap, 10 cache pits, 2 fireplaces, and 8 other test pits excavated, and the site was mapped. Pottery consisted of Stanley Ware, Russell Ware, and Thomas Riggs Ware, and a few objects of historic origin were found. They are the only two sites in the Little Bend area that suggest occupation during the long, rectangular-house period.

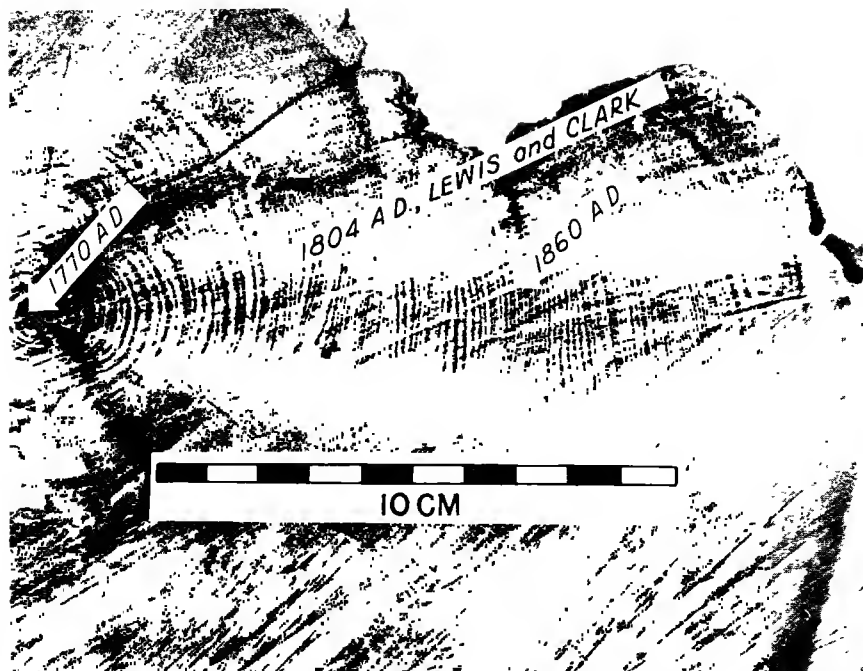
Site 39SL19, located on the floodplain, was a compact village with deep depressions surrounded by a semicircular fortification ditch.



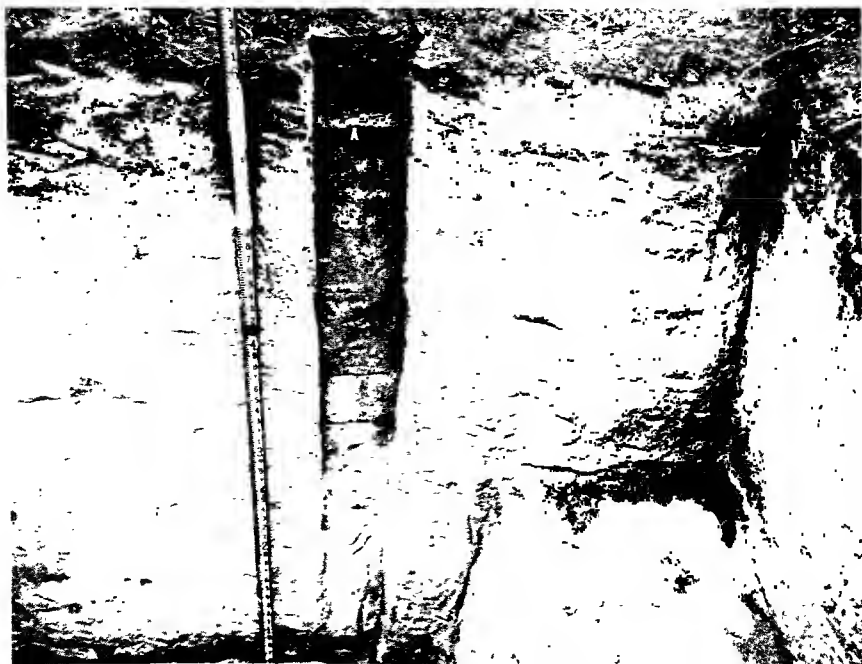
1. Test excavation in site 39SL19, a large village of circular earthlodges, in the Little Bend area of the Oahe Reservoir, producing Stanley Ware pottery. Examples of architectural style, settlement pattern, and artifact materials can be obtained by a series of tests of this kind at each site. River Basin Surveys.



2. Expanded test excavation in edge of circular house at site 39SL13, in the Little Bend area of the Oahe Reservoir. Center of house is to right of picture. A leaner post of the house wall can be seen to right of menu board. Large excavated cache pit is shown in center of picture and an unexcavated cache pit appears as dark semicircle at left. River Basin Surveys.



1. Section of a large cedar (*Juniperus*) cut by a Missouri Basin Project-Smithsonian Institution field party in 1958. The tree stood high on the bluffs overlooking the "Grand Detour," the great loop of the Missouri now called the Big Bend. The earliest annual ring dates from ca. A.D. 1770. This log provides a fine illustration of variable tree growth in response to varying rainfall. The drought years of the 1840's and the 1930's are plainly visible. River Basin Surveys.



2. View of soil profile section in site 39BF2, a deeply buried, multicomponent site in the Big Bend Reservoir. Soil samples were taken from seven zones in this cut to assist in determining the geologic-climatic periods of the various occupations. River Basin Surveys.

Tests were made in one midden heap, a cache pit, and eight other test pits, and the site was mapped. An extensive sample of Stanley Ware pottery was obtained. Site 39SL3, located on a low terrace, was a compact area of 26 house depressions but no evidence of a fortification ditch or large ceremonial house. Four houses were tested and three cache pits, three fireplaces, and a burial were excavated. The site was mapped. Pottery was of the Stanley Ware and some historic objects were recovered. Site 39SL28, located on the low brush promontory just east of 39SL12, consisted of one large ceremonial house depression and at least seven other smaller house depressions. One house was tested, four middens and two cache pits were excavated, and the site was mapped. Stanley Ware pottery predominated in the collections but some Russell Ware was also found. These three sites and the one multicomponent site listed in the Thomas Riggs group above were the only sites with a predominance of Stanley Ware pottery.

At the following sites Russell Ware pottery predominated. Site 39SL8, situated on a low terrace, represents a diffuse village of numerous house depressions. Three houses were tested, and one midden, three cache pits, one fireplace, and one test pit were excavated, and the site was mapped. Site 39SL30 consisted of two very shallow house depressions on a low terrace promontory. One house was tested, and two middens and a fireplace were excavated. A map was made of the site. Site 39SL24 was a small, compact village containing one large ceremonial house depression and at least five smaller depressions located on the low terrace above the floodplain. Four houses were tested, a midden, a fireplace, and a cache pit were excavated, and the site was mapped. Site 39SL202, the remains of another village situated on a low terrace above the floodplain, consisted of two rather large, ringed house depressions. Both houses were tested, two middens, and two fireplaces were excavated, and the site was mapped. Site 39SL36 contained only one very faint house depression on a high (or second) terrace and a small rock cairn. The house was tested, four middens and a fireplace were excavated, and the site was mapped. It was a small, poor site but some additional house depressions may have been present. Site 39SL50, newly located in 1959, consisted of two shallow house depressions on a small terrace promontory. One house was tested, a midden and a test pit were excavated, and the site was mapped. It was a small, unproductive site. Site 39SL23 consisted of a large ceremonial house depression and 17 smaller house depressions located on a high (or second) terrace above the floodplain. A considerable quantity of collared rim sherds were present in the collections. Three houses were tested, a midden, four cache pits, and two test pits were excavated, and the site was mapped. Site 39SL21 was a single house

depression and two rock cairns located on the high terrace. Tests of cairns were negative. The house was tested, two cache pits, a fireplace, and two test pits were excavated, and the site was mapped. Site 39SL22 was a large ceremonial house depression and three smaller depressions situated on the high terrace. One house was tested, two cache pits, a fireplace, and two test pits were excavated, and the site was mapped. Site 39SL20, consisting of two faint house depressions on the lower terrace, was a small site and not very productive. One house was tested, a midden, a cache pit, and two fireplaces were excavated, and the site was mapped. Site 39SL17 contained a large ceremonial house and six smaller depressions on the high terrace. Three houses were tested, two cache pits, a fireplace, and a test pit were excavated, and the site was mapped. Site 39SL16 was composed of three shallow house depressions and several other irregular depressions situated on the high terrace. Two houses were tested, a cache pit and a fireplace were excavated, and the site was mapped. This was a small and unproductive site. Site 39SL14 contained two house depressions on the high terrace adjacent to Site 39SL13. Both houses were tested, a midden was excavated, and the site was mapped. Site 39SL34, a single house depression on the high terrace and a part of the 39SL13 and 14 complex, was not productive. The house was tested, a midden was excavated, and the site was mapped.

Ten sites, newly located in 1959, consisted of only minor-find spots of specimens, random fire hearths, cache pits, and similar isolated features. None is of enough significance to warrant further attention, though surface collections and/or minor tests were made in all of them. These sites are 39SL47, 48, 49, 51, 52, 53, 54, 55, 56, and 57. Likewise, site 39SL25 was examined and written off as of no further interest. Thus by the end of the season tests had been made to provide architectural details for 36 circular earth lodges in 17 separate sites and excavations had been conducted in 25 middens, 33 cache pits, 16 fireplaces, and 26 random test pits. One burial was recovered and 19 sites were mapped. Houses were consistently tested by excavating a trapezoidal area on the depression edge with the base of the trapezoid (10–25 feet wide) just outside the house ring and the smaller base (5–10 feet) near the center. This gave maximal coverage of the house periphery. In many cases these tests were extended to the central fireplace, and where the wall post pattern seemed unsatisfactory the outer edge of the trapezoid was extended. The McNutt party completed its season's work on August 29, after 8½ weeks in the field.

The fourth River Basin Surveys party for the 1959 season was directed by Dr. Alfred W. Bowers. This crew of five began intensive excavations at the Anton Rygh site (39CA4), in Campbell County, South Dakota, on July 13, and continuing the investigations that were

carried on by Dr. Bowers during the previous two summers. The objective for this final season was the excavation of portions of the early, long-rectangular house component that underlay at least three later occupations of circular earth-lodge villages. This objective was only partially achieved. Portions of a rectangular house wall were uncovered, and a substantial series of early ceramic types of the Thomas Riggs-Huff sequence was collected. In addition to this, a major contribution to an understanding of this type of prehistoric site was made in the excavation of a sequence of fortifications and defensive structures especially equipped with bastions and "strong points." Two distinctive fortification systems separated by 4 to 5 feet of fill were identified. The upper one is associated with late Alaska material and represents one style of fortification in use in earliest historic times. The lower system is associated with the Thomas Riggs-Lower Fort Yates material of the rectangular house period of seven or eight centuries ago. The Bowers party completed its season's work on August 22, after six weeks in the field.

Two Missouri Basin Project field parties were in operation for brief periods during the winter months. In response to notification by the area engineer at Gavins Point Dam that an archeological site was being destroyed by wave action at Lewis and Clark Lake, Robert W. Neuman visited the site in company with Corps of Engineers personnel during the period December 2-5. Brief testing of the Miller Creek site (25KX15) demonstrated that it was a campsite of the period prior to the sedentary earth-lodge villages in the area and may be of considerable significance when excavated later in conjunction with proposed bank stabilization work by the Corps of Engineers. The fine cooperation of the Corps of Engineers staff was most helpful in this project. In addition to work at the Miller Creek site, Neuman visited a burial-mound group near Mitchell, S. Dak., where unauthorized digging had been reported, and found that one of the mounds had been destroyed. The landowner agreed to allow no further unauthorized excavation there. The trip was completed with a brief survey of the construction activities at the Big Bend Dam.

The second wintertime field party in the Missouri Basin also went to the Miller Creek site (25KX15). This was a cooperative project between the River Basin Surveys, the University of Nebraska Laboratory of Anthropology, and the Corps of Engineers, U.S. Army, at the Gavins Point Dam. The area engineer advised that bank-stabilization work would begin in the area of this site the week of February 15. During the period February 12-20, Robert W. Neuman, of the River Basin Surveys staff, and Thomas A. Witty, of the University of Nebraska Laboratory of Anthropology, excavated a portion of the site. They were assisted by the area engineer, the reservoir naturalist,

and the reservoir manager of the Gavins Point Dam. The Laboratory of Anthropology provided a part of the field expenses. This is another example of the outstandingly fine cooperation between various Federal and State agencies in the Inter-Agency Archeological Salvage Program. The Miller Creek site, on the right bank of Miller Creek at its confluence with the Missouri River in Knox County, Nebraska, is a prehistoric Indian campsite exposed at a depth of from 3 to 6 feet below the surface. Test trenches revealed a moderate quantity of artifacts including chopping tools, projectile points with and without side notches, and a few pottery fragments. The material relates the site to the Woodland cultures. In addition, a day was spent at a site on the South Dakota side of Lewis and Clark Lake, collecting some deeply buried bison bones that appear to be of an extinct species.

The 1960 summer field season in the Missouri Basin began in the Big Bend Reservoir area on June 8. Dr. Warren W. Caldwell and the party under his direction, prevented by heavy rains and unexpected high water from reaching its primary objective of sites in Old Armstrong County, Oahe Reservoir, temporarily transferred their activities for the early part of the season to the area about the mouth of Medicine Creek in Lyman County, South Dakota. By the end of the fiscal year Caldwell had a crew of eight men, and excavations were well underway at Sites 39LM222 and 39LM224, two small earth-lodge villages briefly tested in the 1959 season.

The second Missouri Basin Project field party starting work in June was under the direction of Robert W. Neuman. It was engaged in the excavation of a burial-mound site near the North Dakota-South Dakota State line, in the Oahe Reservoir area, Sioux County, North Dakota. This site, the Boundary Mound group (32SI1), consists of several burial mounds of the Plains Woodland period, and is one of the extensive series of Woodland mound sites in the Oahe Reservoir area scheduled for excavation by this party during the 1960 season. By the end of the year excavations at this site were nearly completed. Mr. Neuman and his crew of six men had cut extensive trenches across three of the mounds and had dug several test pits in other parts of the site.

The third Missouri Basin Project field party at work in June was a crew of three under the direction of G. Hubert Smith in the Oahe Reservoir area. This historic-sites party planned to begin digging on June 23 at the site of old Fort Bennett (39ST26) in Stanley County, South Dakota. When it reached that location, however, it found most of it already under water and a change was necessary. The party moved to Fort Sully (39SL45) in Sully County on the other side of the Missouri River, and on June 28 started an investigation of the foundations and refuse dumps at that historic military post in order to

verify several ground plans of the post and gather a representative series of specimen materials of the period.

Cooperating institutions working in the Missouri Basin at the beginning of the fiscal year included a party from the University of Kansas, directed by Dr. Carlyle S. Smith, excavating at the Stricker Village site (39LM1) in the Big Bend Reservoir and testing two nearby sites, 39LM226 and 39LM227; a joint party from the University of North Dakota and the State Historical Society of North Dakota, directed by Dr. James H. Howard, excavating at the Huff site (32MO11) in the Oahe Reservoir area; and two parties from the University of Missouri, directed by Dr. Carl F. Chapman, excavating a series of sites in the Pomme de Terre Reservoir area and making preliminary surveys in the Kassinger Bluff Reservoir area of west-central Missouri. In July and August, a party from the Kansas State Historical Society, under the direction of Roscoe Wilmeth, excavated one site and tested three others in the Pomona Reservoir area of east-central Kansas. In October a party from the University of South Dakota, directed by William Buckles, excavated a cemetery area at the Four Bears site (39DW2) in the Oahe Reservoir area of South Dakota. In April the Nebraska State Historical Society had a party, under the direction of Marvin F. Kivett, surveying sites in the Red Willow Reservoir in southwestern Nebraska. At the end of the fiscal year, four cooperating institutions had archeological crews in the field: The State Historical Society of North Dakota, at the Huff site (32MO11) in the Oahe Reservoir area, under the direction of W. Raymond Wood; the University of Nebraska, at the Leavenworth site (39CO9) in the Oahe Reservoir area, directed by Dr. Preston Holder; the University of Missouri, surveying and testing sites in the Kassinger Bluff Reservoir area, directed by Dr. Carl F. Chapman; and the Kansas State Historical Society, in the Wilson Reservoir area in central Kansas, directed by Roscoe Wilmeth. All these parties were operating through agreements with the National Park Service and were cooperating in the Smithsonian Institution research program.

During the time that the archeologists were not in the field, they were engaged in analysis of their materials and in laboratory and library research. They also prepared manuscripts of technical, scientific reports and wrote articles and papers of a more popular nature.

The Missouri Basin Chronology Program, started by the staff archeologists of the Missouri Basin Project in January of 1958, and described in the Seventy-sixth Annual Report of the Bureau of American Ethnology, continued to operate throughout the year. The program has continued to have marked success and the entire group of 34 individuals and 20 research institutions has continued to co-

operate in assembling data, under the general direction of the Missouri Basin Project staff members. Studies by Dr. Paul B. Sears of Yale University on the pollen samples collected last year have continued to progress, and at least one profile is being verified. Another group of 11 radioactive carbon-14 samples has been submitted to the University of Michigan Memorial Phoenix Laboratory, under the direction of Professor H. R. Crane, to add to the 11 dates already obtained on carbon-14 specimens. Plans for full-time participation by a dendrochronologist made little headway during the year but look promising for next year. On a part-time basis, the dendrochronologist, Harry E. Weakley, continued to prepare materials for study. Alan H. Coogan, though no longer a member of the River Basin Surveys staff, continued his studies of the geologic-climatic aspects of the chronology of the terrace-situated sites in the Fort Thompson region of the Big Bend Reservoir area. The 11 radiocarbon dates already obtained in the Missouri Basin Chronology Program are given in their relative temporal positions in table 1. The dendrochronological material is illustrated in plate 2, figure 1, and the soil profile of a site near Fort Thompson, S. Dak., is shown in plate 2, figure 2, to illustrate the geologic-climatic approach to the dating of archeological materials.

The laboratory and office staff spent its full effort during the year in processing specimen materials for study, photographing and illustrating specimens, preparing specimen records, and typing, filing, and illustrating records and manuscript materials. The accomplishments of the laboratory and office staff are listed in tables 2 and 3.

As of June 30, 1960, the Missouri Basin Project laboratory had cataloged 1,219,563 specimens from 2,097 numbered sites and 58 collections not assigned site numbers in the 14 years of its operation. It may be noted in table 2 that considerable material from the Chattahoochee River Basin was processed in the Missouri Basin Project laboratory this year. This reflects collaboration for expediency and economy between the archeological investigations outside the Missouri River Basin and the facilities for work within the Missouri Basin and constitutes a major contribution to the effectiveness of the salvage program in the southeastern United States. In addition to the processing of these specimens, the Missouri Basin Project facilities were utilized for a portion of the year in the preparation of maps, illustrations, and the three mimeographed appraisal reports resulting from the work in the Chattahoochee Basin last year. Without the aid of the Missouri Basin Project facilities these researches would not have progressed so rapidly.

The Missouri Basin Project staff archeologists and archeologists of the National Park Service and the cooperating State agencies working in the Missouri Basin met on July 24 in a roundtable field conference

Table 1.—Carbon-14 dates obtained by the Missouri Basin Chronology Program.

NEBRASKA	DATE (A.D.)	SOUTH DAKOTA
<p>a. Lynch Site; a village of square houses with rounded corners, in Boyd County. Sample: charcoal from general digging; dates a late occupation 250±150 years old, or 1708 A.D., ±150 years</p>	<p>-1800- -1700-</p>	<p>f. Cheyenne River Site (first occupation); a village of long, rectangular houses in Stanley County (Oahe Reservoir). Sample: burned house-post. 650±200 years old, or 1308 A.D., ±200 years</p>
<p>b. Site 25FT70; a small cluster of square houses in Frontier County (Medicine Creek Reservoir). Sample: charcoal from a house floor. 500±200 years old, or 1458 A.D., ±200 years</p>	<p>-1600- -1500-</p>	<p>g. Thomas Riggs Site; village of long, rectangular houses in Hughes County (Oahe Reservoir). Sample: burned house-post. 730±200 years old, or 1228 A.D., ±200 years</p>
<p>c. Coufal Site; a village of square houses in Howard County. Sample: burned roof-support post from a house. 820±200 years old, or 1138 A.D., ±200 years</p>	<p>-1400- -1300-</p>	<p>h. Dodd Site (second occupation); a village of long, rectangular houses in Stanley County (Oahe Reservoir). Sample: partly burned wall-post from a house. 800±200 years old, or 1158 A.D., ±200 years</p>
<p>d. Site 25FT18; a small cluster of houses with circular floor areas, in Frontier County (Medicine Creek Reservoir). Sample: charcoal from several posts and other features. 1130±200 years old, or 828 A.D., ±200 years</p>	<p>-1200- -1100-</p>	<p>i. Crow Creek Site (first occupation); two long, rectangular houses, in Buffalo County (Fort Randall Reservoir). Sample: charcoal from two roof-support posts in one of the houses 900±200 years old, or 1058 A.D., ±200 years</p>
<p>a. Logan Creek Site; an ancient campsite in Burt County. No houses were found. Sample: charcoal from second level of site fill. 6533±300 years old, or 4674 B.C., ±300 years</p>	<p>-1000- -900- -800- -700- -600-</p>	<p>j. Swanson Site; a village of long, rectangular houses in Brule County (Fort Randall Reservoir). Sample: burned wall-post from one of the houses. 1100±250 years old, or 358 A.D., ±250 years</p>
<p>c. 4674 B.C.</p>	<p>-800- -700- -600-</p>	<p>k. Breeden Site (first occupation); village of long, rectangular houses in Stanley County (Oahe Reservoir). Sample: charcoal found in a storage pit in a house. 1240±150 years old, or 719 A.D., ±150 years</p>

TABLE 2.—*Specimens processed July 1, 1959–June 30, 1960*

Reservoir	Number of sites	Catalog numbers assigned	Number of specimens processed
MISSOURI BASIN PROJECT			
Big Bend.....	17	404	1, 357
Fort Randall.....	1	7	20
Oahe.....	50	5, 098	43, 437
Sites not in reservoirs.....	3	9	26
	71	5, 518	44, 840
Collections not assigned site numbers.....	3	5	5
Total.....		5, 523	44, 845
CHATTahoochee BASIN			
Columbia Dam.....	33	4, 053	30, 161
Walter F. George.....	282	5, 170	65, 779
Oliver.....	11	128	2, 968
Sites not in reservoirs.....	2	83	1, 254
	328	9, 434	100, 162
Collections not assigned site numbers.....	1	29	138
Total.....		9, 463	100, 300
Combined totals.....	399	14, 986	145, 145

TABLE 3.—*Record material processed July 1, 1959–June 30, 1960*

MISSOURI BASIN PROJECT

Reflex copies of records.....	10, 299
Photographic negatives made.....	1, 781
Photographic prints made.....	9, 945
Photographic prints mounted and filed.....	3, 654
Transparencies mounted in glass.....	283
Kodachrome pictures taken.....	454
Plate layouts made for manuscripts.....	69
Cartographic tracings and draftings.....	50
Artifacts sketched.....	44
Plates lettered.....	37
Profiles drawn.....	36

in Pierre, S. Dak. This 16½th Plains Conference, now a regular summer event, and an adjunct of the annual autumnal Plains Conferences, was devoted to discussions of basic technical problems arising from current field activities. They centered principally around the sequences of cultural groupings in this area and the interrelationships between the several cultural manifestations represented by excavated materials. During the Thanksgiving weekend, members of the staff participated in the 17th Plains Conference for Archeology, held in Lincoln. On April 23, members of the staff took part in the Seventieth Annual Meeting of the Nebraska Academy of Sciences, held also in Lincoln.

Dr. Robert L. Stephenson, chief, devoted considerable time to managing the office and laboratory in Lincoln and preparing plans and budgets for the 1960 field season. He also worked on a summary report of the Missouri Basin Salvage Program for the calendar years 1952-60, and on a complete revision of a large technical monograph, "The Accokeek Creek Site: A Middle Atlantic Seaboard Culture Sequence," previously accepted as his doctoral dissertation at the University of Michigan. He began preparation of an article, "Administration in Anthropology," and started preliminary analysis of the materials he recovered from the excavations at the Sully site (39SL4) in the Oahe Reservoir in 1956 to 1958. He also continued writing on the manuscript reporting the "Archeological Investigations in the Whitney Reservoir, Texas." Throughout the year he served as chairman of the Missouri Basin Chronology Program. In July he served as chairman of the 16½th Plains Conference held in Pierre, S. Dak., and during the Thanksgiving weekend served as general chairman for the 17th Plains Conference held in Lincoln, Nebr. He was a panel discussant for "The Texas Panhandle and the Southwest" in the session on "Plains-Southwest Relationships," and presented an exhibit of "The History of the Plains Conference" at that meeting. On January 20 and 21, he participated in the annual meeting of the Committee for the Recovery of Archeological Remains, held in Washington, D.C., and on April 23, he attended the Seventieth Annual Meeting of the Nebraska Academy of Sciences in Lincoln, presenting a paper on "A Ceramic Dichotomy" which was published in abstract in the *Proceedings of the Nebraska Academy of Sciences*. During the year he prepared a book review of "The Cougar Mountain Cave," by John Cowles, for publication in *American Antiquity*, and a book review of "Archeology of Coastal North Carolina," by William Haag, for publication in *Ethnohistory*. He also gave nine talks on various aspects of Missouri Basin Salvage Archeology at the regular meetings of local civic organizations and three talks to local school groups in Lincoln. On

March 1, he became assistant editor of *Notes and News in the Plains Area*, for *American Antiquity*, and on April 29, was appointed associate editor for the *Plains Anthropologist*. Taking annual leave, he served as part-time assistant professor of anthropology on the faculty of the University of Nebraska during the second semester of the academic year (February to June) and taught an upper-division course, "Prehistory of North America."

Dr. Warren W. Caldwell, archeologist, when not in charge of field parties, devoted most of his time to analyses of specimen materials he had recovered from salvage excavations in previous years. He completed preliminary analysis of the ceramics and certain other artifacts from the Black Partizan site (39LM218) which he excavated in the Big Bend Reservoir in 1958. He reanalyzed the artifacts and data from the Hickey Brothers site (39LM4), excavated by Bernard Golden of the Missouri Basin Project staff in 1958, and in collaboration with Lee G. Madison and Bernard Golden completed the final manuscript, including figures and illustrations, "Archeological Investigations at the Hickey Brothers Site (39LM4), Big Bend Reservoir, South Dakota." He reanalyzed the artifacts and stratigraphic data from the Wakemap Mound site (45KL26), and prepared introductory chapters for the final report on the excavations there; completed the final revision of the report, "Archeological Investigations in the Hell's Canyon Area, Snake River, Oregon and Idaho"; revised and completed the manuscripts and illustrations for a popular photographic booklet, "Lewis and Clark Lake," which was published by the Corps of Engineers, U.S. Department of the Army, Omaha, Nebr., in January. In collaboration with Charles H. McNutt and G. Hubert Smith, he contributed chapters to, edited, and completed final revision of a similar popular booklet, "Fort Randall Reservoir." The latter was submitted to the Corps of Engineers in Omaha for publication. He revised three manuscripts of short articles pertaining to firearms in the Plains: "Preliminary Notes on Fragments of Firearms and Related Objects from Fort Atkinson, 1820-1827," "Firearms and Related Materials from Fort Pierre II (39ST217), Oahe Reservoir, South Dakota," and "Comments on the 'English Pattern' Trade Rifle." They were submitted for publication in the *Missouri Archeologist*. Other manuscripts and publications completed by him this year were: "The Black Partizan Site, A Preliminary Anaylsis," accepted for publication in the *Plains Anthropologist*; review of "Stone Age on the Columbia," by Emory Strong, accepted for publication in *Archeology*; review of "Archeological Explorations in Central and South Idaho, 1958," by Earl H. Swanson, Jr., Donald R. Tuohy, and Alan Bryan, accepted for publication in *American Antiquity*; "Pacific Coast Clay Figurines: A Contraview," published

in the *Davidson Journal of Anthropology*, vol. 3, No. 2; and a mimeographed statement issued by the Missouri Basin Project, "Missouri Basin Project, Progress Report No. 4." On July 24, he participated in the 16½th Plains Conference in Pierre, S. Dak., and November 26-28 attended the 17th Plains Conference for Archeology in Lincoln, where he served as chairman of the session on "Field Reports" and presented a paper, "Excavations in the Lower Brule-Good Soldier Creek Area, Big Bend Reservoir." On April 23 he presented a paper, "Clay Figurines in the Prehistory of the Northwest," before the Nebraska Academy of Sciences in Lincoln. It was published in abstract in the *Proceedings* of the Academy. During the year he continued to serve as chairman of the dendrochronology section of the Missouri Basin Chronology Program. In February, he accepted appointment as collaborator for the Plains area for *Abstracts of New World Archeology*, and in April accepted appointment as assistant editor for Reviews and Literature for the *Plains Anthropologist*. In March he addressed the Sigma Gamma Epsilon, national earth-sciences honorary, on "The Smithsonian Institution and the Archeological Salvage Program." On annual-leave time, he served as part-time assistant professor of anthropology on the faculty of the University of Nebraska during the second semester of the academic year (February to June) and taught a lower-division course, "The American Indian."

Dr. Charles H. McNutt, archeologist, when not in the field conducting archeological excavations, spent much of his time in studying materials he had obtained in previous seasons and in the preparation of reports on the results of those excavations. He attended and participated in the 16½th Plains Conference in Pierre in July, and the 17th Plains Conference for Archeology in Lincoln in November. At the latter he presented two papers, "The Thomas Riggs Focus, Additional Data" and "Comments on Two Southwestern Pottery Types." In April he attended the Seventieth Annual Meeting of the Nebraska Academy of Sciences and presented a paper, "Comments on Prehistoric Contacts between the Southwestern United States and the Areas to the East." It was published in abstract in the *Proceedings* of the Academy. In September he prepared an article, "The Missouri Basin Chronology Program," which appeared in the *Progress Report* of the Interior Missouri Basin Field Committee for October-December 1959. In January he collaborated with Warren W. Caldwell and G. Hubert Smith in the preparation of a popular photographic booklet, "Fort Randall Reservoir," to be published by the Corps of Engineers, Omaha. Throughout the year he served as chairman of the carbon-14 section of the Missouri Basin Chronology Program. During the course of the year he completed manuscripts on "The Okobojo

Creek Site (39SL9), Oahe Reservoir," "The Ziltener Site (39SL10), Oahe Reservoir," "The Nolz Site (39SL40), Oahe Reservoir," and "The Glasshoff Site (39SL42), Oahe Reservoir." He also completed the final draft of the report, "The C. B. Smith Site (39SL29), Oahe Reservoir." All five of these are now ready for publication. In addition, he completed the artifact analyses and portions of the manuscripts of reports of work at the "Sully School Site (39SL7), Oahe Reservoir" and "The Zimmerman Site (39SL41), Oahe Reservoir." On his own time during the second semester of the academic year (February to June), he served as part-time assistant professor of anthropology on the faculty of the University of Nebraska and taught a lower-division course, "World Ethnology." On May 27, he resigned from the River Basin Surveys to accept a teaching position at the University of Tennessee.

William M. Bass III, temporary physical anthropologist, attended and participated in the 16½th Plains Conference in Pierre and after completion of his fieldwork resigned on August 28. During the remainder of the year he devoted much of his own time to study of the data collected in the field and to statistical analyses of the measurements taken on the human skeletal material from the Plains. These data will provide the basis for his doctoral dissertation at the University of Pennsylvania and also for an extensive handbook on the physical anthropology of the Plains Indians.

William N. Irving spent the months of July and August in the Lincoln laboratory completing a first draft of a technical report on his excavations at the Medicine Crow site (39BF2) in the Big Bend Reservoir area. He resigned on September 4 to continue his studies toward a doctorate at the University of Wisconsin.

Dr. Alfred W. Bowers, temporary archeologist, attended and participated in the 16½th Plains Conference in Pierre in July. He resigned on August 28 to return to his regular position as professor of anthropology at the University of Idaho. During the course of the year he devoted a portion of his time to analysis of the archeological materials he had excavated during the past three summers at the Anton Rygh site (39CA4) in the Oahe Reservoir.

Robert W. Neuman, archeologist, when not engaged in field activities, turned his attention to analysis and interpretation of archeological materials from sites he had previously excavated in the Big Bend Reservoir area of South Dakota. He completed a manuscript "The Truman Mound Site (39BF224), Big Bend Reservoir Area, South Dakota" and a brief article on "Representative Porcupine Quill Flatteners from the Central United States," both of which were accepted for publication in *American Antiquity*. He prepared and published a brief article in the *Florida Anthropologist* entitled "Two Unrecorded Pottery Vessels from the Purcell Landing Site, Henry

County, Alabama." He completed the analysis of specimen materials and prepared final drafts of two manuscripts reporting sites he had excavated in the 1958 and 1959 seasons: "The Good Soldier Creek Site (39LM238), Lyman County, South Dakota" and "Two Sites in the Fort Thompson Area, Big Bend Reservoir, South Dakota." The former deals with a stratified site of Plains Woodland occupation overlain by a Mississippian component. The latter reports the investigations at a burial mound site of Plains Woodland context and at a multicomponent village site. In November he attended the 17th Plains Conference for Archeology in Lincoln, and in April he presented a paper, "Burial Patterns in Mounds of the Big Bend Area, Central South Dakota," at the Seventieth Annual Meeting of the Nebraska Academy of Sciences in Lincoln. This paper was published in abstract in the *Proceedings* of the Academy. In March he was elected to full membership in the Society of the Sigma Xi and was initiated in May. At the end of the year he was again in the field in charge of a crew excavating burial mounds in the Oahe Reservoir area.

G. Hubert Smith, archeologist, was on duty at the Lincoln office most of the year. In July he participated in the 16½th Plains Conference in Pierre, and in November he attended the 17th Plains Conference for Archeology in Lincoln, serving as a discussant in a panel forum on "Plains Ethnohistory." He visited the State Historical Society of North Dakota in Bismarck during the period November 9-14 for the purpose of examining and borrowing field notes and specimens pertaining to the large technical manuscript he is preparing on the combined researches at the site of Fort Berthold and Like-a-Fishhook Village (32ML2). The work on this report on four seasons of investigation by three separate State and Federal agencies at this site occupied Mr. Smith the major part of the year. It was about two-thirds completed by June 30, 1960. On April 2, he was lent to the National Park Service at Colonial National Historical Park, Yorktown, Va., where he conducted excavations at the site of an early 18th-century dwelling and completed a comprehensive technical report of the results. In April he contributed a paper, in absentia, on "Historical Archeology in Missouri Basin Reservoir Areas; Current Investigations" for the Twentieth Annual Meeting of the Nebraska Academy of Sciences. It was published in abstract in the *Proceedings* of the Academy and was accepted for publication in its entirety in the *Plains Anthropologist*. As previously mentioned, he collaborated with Caldwell and McNutt in the preparation of a popular booklet on "Fort Randall Reservoir." He wrote a review of "The Indian Journals of Lewis Henry Morgan—1859-1862," edited by Leslie A. White, which was accepted for publication in *Nebraska History*. In March he was elected to full membership in the Society of the Sigma Xi, and initiated, in absentia, in May. He returned to his duties in

Lincoln on June 1 and began preparations for the summer fieldwork. At the end of the year he was conducting investigations in historic sites in the Oahe Reservoir area.

West Virginia.—A survey of the Sutton Reservoir (Cleveland M. Bailey Reservoir) on the Elk River in West Virginia was made during the period October 8–19. With the helpful cooperation of the Corps of Engineers the entire area was covered on foot and by vehicle and no archeological manifestations were found. This was one of the few areas investigated where no further work would be required.

Cooperating institutions.—In addition to the institutions and agencies previously mentioned in the sections pertaining to Alabama-Georgia and Missouri Basin, a number of others cooperated in the Inter-Agency Salvage Program in several areas throughout the United States. The University of Arkansas made an archeological survey in the Beaver Reservoir area on the White River and carried on geological and paleontological investigations in the Greers Ferry Reservoir basin on the Little Red River. The University of Arizona continued its excavations in the Painted Rock project area on the Gila River. The Northern Arizona Museum of Science and Art made additional studies relating to the archeology, geology, flora, and fauna of the Glen Canyon project in the lower Colorado and San Juan Rivers. Southern Illinois University made a series of excavations in the Carlyle Reservoir basin on the Kaskaskia River in Illinois. The University of Kentucky conducted excavations in the Barkley Reservoir area on the Cumberland River and at the Barren No. 2 project on the Barren River. It also conducted a survey of 22 small Federal projects scattered over the State of Kentucky. The University of Missouri carried on investigations in the Joanna Reservoir area on the Salt River in the Upper Mississippi Basin. The Museum of New Mexico again worked in the Navaho project area along the San Juan River. The University of North Carolina conducted surveys and excavations in the Wilkesboro Reservoir area on the Yadkin River. San Francisco State College conducted excavations at the Black Butte project on Stony Creek and in the San Luis Reservoir area above the juncture of San Luis and Cottonwood Creeks in Merced County, California. The University of Oregon continued its series of excavations in the John Day Reservoir area on the John Day River in the Columbia basin. Nevada State Museum made a survey of the Peavine Mountain Water Shed project in Nevada, and Washington State College carried on additional excavations in the Ice Harbor Reservoir area on the Snake River. The University of Texas made surveys in the Proctor Reservoir area on the Brazos River, the Navarro Mills project on Richland Creek, and the proposed reservoir areas on Flat Creek, Farmers' Creek, and Champion Creek. In addition it conducted

excavations at the Ferrell's Bridge project on Cypress Creek at the Whitney Reservoir on the Brazos River and in the Diablo Reservoir region along the Rio Grande. It also investigated remains in the Canyon and Iron Bridge project areas. East Texas State College made paleontological surveys in the Iron Bridge area along the Sabine River and the Panhandle-Plains Museum made surveys in the Greenbelt Reservoir area. The University of Utah continued its excavations in the upper portions of the Glen Canyon Reservoir area on the Colorado River.

During the year various local groups and institutions continued to cooperate in the salvage program on a voluntary basis. They were mainly in Pennsylvania, New York State, Ohio, Indiana, Tennessee, and southern California.

ARCHIVES

The Bureau Archives continued during the year under the custody of Mrs. Margaret C. Blaker. On November 14 Mrs. Blaker attended meetings of the American Indian Ethnohistoric Conference in New York City and while returning to Washington she spent three days in Philadelphia examining pictorial and manuscript collections relating to American Indians in the American Philosophical Society Library and in the Historical Society of Pennsylvania.

MANUSCRIPT COLLECTIONS

The Bureau's manuscript collections continue to be utilized by anthropologists and other students. About 285 manuscripts were consulted by searchers, of whom 60 visited the archives in person and 28 purchased reproductions totaling 2,346 pages. Some 350 manuscripts were referred to by the archivist in obtaining information for 90 mail inquiries. In the course of this examination, new and more detailed descriptive lists of manuscripts were also prepared and are available for distribution in response to specific inquiries.

The papers of Alice Cunningham Fletcher and her adopted son, Francis La Flesche, which had been deposited on loan in 1955 by Mrs. G. David Pearlman of Washington, D.C., were donated by Mrs. Pearlman in 1959 in memory of her husband, G. David Pearlman. During the year just ended this collection was arranged and cataloged by Nicholas S. Hopkins, summer intern. The collection occupies 36 boxes. In addition to correspondence and other personal papers of both Fletcher and La Flesche, there is extensive ethnographic material relating to the Omaha, Osage, Pawnee, Dakota, and Nez Perce tribes, with smaller amounts on the Winnebago, the Indians of Alaska, and a number of other North American tribes. Much of this material has not been published, and should be helpful

to anyone studying those tribes. A 20-page outline of the subject matter of the collection has been prepared, and further information will be provided on request.

PHOTOGRAPHIC COLLECTIONS

Requests by scholars, publishers, and the general public for ethnographic photographs from the Bureau's collection continue to increase. The year's total of 604 purchase orders and written and personal inquiries concerning photographs is considerably greater than last year's total of 504, and the 1,983 prints distributed during the year through purchase, gift, and exchange represented a marked increase over the 1,208 of the previous year.

As a result of new lists describing specific portions of the photographic collections that are frequently being prepared, much information about available photographs is gradually being distributed, with a corresponding increase in the distribution of photographs. At present about 110 lists have been prepared describing series of photographs relating to individual tribes or subjects. Since these are in typed form only, they are not distributed as complete sets, but copies of the relevant ones are sent in response to specific inquiries.

The Bureau's files of photographs are constantly growing through the generosity and thoughtfulness of interested individuals who either lend their personal collections for copying or present them as gifts. For example, a series of 160 photographic prints relating to the Northern Cheyenne Sun Dances of 1958 and 1959, and to the moving and opening of the Sacred Buffalo Hat bundle in 1958 and 1959, were made from negatives taken and lent by Mrs. Margot Liberty of Birney, Mont. The Bureau's set of prints is available for reference by students, but until 1970 purchase orders for copies will be referred to Mrs. Liberty who retains the negatives.

Arrangements were made by Dr. William C. Sturtevant for borrowing and copying 69 photographs relating to the Florida Seminole taken during the first quarter of the 20th century. They were from the following collections in Florida: Collier Development Corporation, Everglades; the P. K. Yonge Library of Florida History, University of Florida, Gainesville; the Willson-Cantrell Collection, University of Miami Library, Miami; and the personal collections of Frank A. Robinson, Robinson Galleries, Miami; Dr. Charlton W. Tebeau, Miami; and Mrs. M. K. Ashworth, Coral Gables.

Daguerreotypes of Eleazer Williams, Mohawk, and John O'Brien Skenondough, probably an Oneida, made by Mathew Brady in 1853 and owned by the Long Island Historical Society, Brooklyn, New York, were lent for copying through the courtesy of Miss Helen Bolman, librarian of the Society.

Nine photographs relating to various North American Indian tribes and two made by T. H. O'Sullivan in Colombia in 1870 while on the Darien Expedition under Commander Selfridge were lent for copying by James Tubbesing of Winchester, Va.

A collection of 33 photographs relating to St. Francis Mission, Rosebud Agency, South Dakota, and to other Dakota Indian agencies, including portraits of agency personnel, Indian police, students, and agency buildings, were received as a gift from Richard A. Pohrt of Flint, Mich. Eleven photographs by J. N. Choate pertaining to the Carlisle Indian School, Carlisle, Pa., were also donated by Mr. Pohrt.

Nine photographs of Spanish Mission churches in the Southwest and Mexico were donated by George B. Eckhart, Tucson, Ariz.

A large group photograph of a number of Ute Indians who were camping in the Garden of the Gods, Colorado, in 1913 was received as a gift from Dr. Sidney Margolin of Denver, Colo.

An important collection of 312 glass negatives consisting of individual and group portraits of Indian delegates to Washington photographed by C. M. Bell in the period 1874-1890 was purchased from W. T. Boyce of Washington, D.C. Bell's photographic work was well known to his contemporaries, and a cartoon in *Leslie's Weekly* for September 10, 1881, carries the legend, "Photographing an Indian Delegation, in Bell's Studio, for the Government." In recent years, with the exception of a small series of negatives in the Bureau of American Ethnology uncertainly attributed to him (an attribution now confirmed), Bell's Indian photographs have been little known or used, and the whereabouts of his negatives was not known. The plates have not as yet been individually cataloged, but the following tribes are among those represented: Arapaho, Blackfoot, Cheyenne, Chippewa, Comanche, Dakota, Hidatsa, Sauk and Fox, and some of the Plateau tribes.

With the assistance of Kiowa friends and relatives, Dr. Everett R. Rhoades of Oklahoma City, Okla., identified a number of Kiowa portraits in the Bureau files. Father Peter Powell of Chicago, with the aid of John Stands-in-Timber and other Cheyennes, provided identifications and biographical notes on certain Cheyenne photographs. During a visit to the archives William Hall, a Winnebago of Black River Falls, Wis., gave information about a number of Winnebago photographs.

ILLUSTRATIONS

The Bureau's staff artist, E. G. Schumacher, continued to do a wide variety of illustrating for Bureau and other publications of the Smithsonian Institution. In addition, he made text drawings for articles written by staff members on various topics to be issued in local,

national, and foreign periodicals. Most of the illustrations were of an archeological nature, although there was a sizable cross section of scientific and technical art material undertaken. Approximately 379 halftone plates were mounted, revised, restored, retouched and/or lettered, 237 text illustrations drawn, and 66 charts, diagrams, and graphs prepared.

EDITORIAL WORK AND PUBLICATIONS

The Bureau's editorial work continued during the year under the immediate direction of Mrs. Eloise B. Edelen. There were issued one Annual Report and five Bulletins, as follows:

Seventy-sixth Annual Report of the Bureau of American Ethnology, 1958-59. ii + 41 pp., 4 pls. 1960.

Bulletin 143, vol. 7. Index to the Handbook of South American Indians. vi + 286 pp. 1959.

Bulletin 172. The story of a Tlingit community: A problem in the relationship between archeological, ethnological, and historical methods, by Frederica de Laguna. x + 254 pp., 11 pls., 18 figs. 1960.

Bulletin 173. Anthropological Papers Nos. 57-62. iii + 498, 61 pls., 37 figs., 2 maps. 1960.

No. 57. Preceramic and ceramic cultural patterns in northwest Virginia, by C. G. Holland.

No. 58. An introduction to Plains Apache archeology—the Dismal River Aspect, by James H. Gunnerson.

No. 59. The use of the atlatl on Lake Patzcuaro, Michoacan, by M. W. Stirling.

No. 60. A Caroline Islands script, by Saul H. Riesenbergs and Shigeru Kaneshiro.

No. 61. Dakota winter counts as a source of Plains history, by James H. Howard.

No. 62. Stone tipi rings in north-central Montana and the adjacent portion of Alberta, Canada: Their historical, ethnological, and archeological aspects, by Thomas F. Kehoe.

Bulletin 174. An introduction to Kansas archeology, by Waldo R. Wedel. With description of the skeletal remains from Doniphan and Scott Counties, Kansas, by T. D. Stewart. xvii + 723 pp., 97 pls., 109 figs. 1959.

Bulletin 177. Archeological investigations in British Guiana, by Clifford Evans and Betty J. Meggers, xxi + 418 pp., 68 pls., 127 figs. 1960.

Publications distributed totaled 31,547, as compared with 27,721 for the fiscal year 1959.

COLLECTIONS

The following collections were made by staff members of the Bureau of American Ethnology or of the River Basin Surveys and transferred to the permanent collections of the department of anthropology and the department of zoology, U.S. National Museum:

FROM BUREAU OF AMERICAN ETHNOLOGY

Acc. No.

228466. 318 items of archeological materials from La Venta, Tabasco, Mexico, collected by Robert F. Heizer, Philip Drucker, and Robert J. Squier in 1955.
228740. 183 items of archeological material from Colville River drainage area, northern Alaska, collected by U.S. Geological Survey members, 1949-1950. Reported and turned over to Ralph S. Solecki for transfer.
228741. 351 items of archeological material from along Kukpowruk and Kokolik Rivers, Alaska, collected by Ralph S. Solecki, 1949.

FROM RIVER BASIN SURVEYS

221942. 5 fresh-water mussels from Hughes County, S. Dak., collected by Richard Wheeler and Harold A. Huscher in 1958.
- 226498, 228124, 228919, 229853, 229854, 229855, 229856, 229857, 229861, 229862, 230198, 230201, 230203, 230204. Archeological and human skeletal material collected in Oahe Reservoir, Campbell, Stanley, and Sully Counties, S. Dak.
- 229858, 229859, 229860, 230200. Indian skeletal material from Big Bend Reservoir, Buffalo and Lynn Counties, S. Dak.
230199. Indian skeletal material from Gavins Point Reservoir, Yankton City, S. Dak.
230202. Indian skeletal material from Jamestown Reservoir, Stutsman City, N. Dak.

MISCELLANEOUS

On January 27, 1960, Miss Jean E. Carter was appointed temporarily as museum aide and assigned to the Bureau Archives. She resigned effective May 4, 1960, and on May 23 Mrs. Caroline R. Cohen was appointed for a 3-month period to fill the vacancy. Raymond E. Machoian was also engaged for three months to assist with the cleaning, sorting, and processing of archeological materials excavated at Russell Cave, Alabama.

Dr. John P. Harrington, Dr. A. J. Waring, and Sister Inez Hilger continued as research associates. Dr. M. W. Stirling, also a research associate, continued to use the Bureau laboratory in completing reports on fieldwork undertaken while he was Director of the Bureau.

The following bibliographies and leaflets were issued during the fiscal year:

SIL-65, 2d rev., 10/59: Introductory bibliography on the American Indian. 6 pp.

SIL-230, 9/59: Selected references on American Indian basketry. Compiled by William C. Sturtevant. 7 pp.

SIL-231, 8/59: Bibliography of wild food plants of United States Indians. Prepared by F. R. Irvine. 26 pp.

SIL-234, 10/59: Selected references on North American Indian clothing. Compiled by William C. Sturtevant. 4 pp.

SIL-240, 10/59: Manuscript collection, Bureau of American Ethnology Archives.
1 p.

SIL-242, 11/59: Selected references on federal Indian policy and administration. Compiled by William C. Sturtevant. 10 pp.

A new bibliographic series titled "Smithsonian Anthropological Bibliographies" was inaugurated under the auspices of Dr. William C. Sturtevant of the Bureau staff. This will include bibliographies of varying length and technicality, both areal and topical, in all fields of anthropology, and will be distributed to those requesting it. It is hoped that individuals not affiliated with the Smithsonian Institution who have prepared bibliographies for class use or other purposes which might be of general usefulness will submit them to the Bureau for consideration. No. 1 of the series is "Selected References on the Plains Indians," 36 pages, multilithed, compiled by John C. Ewers. As in other recent Bureau bibliographies, this one includes recordings of music, sources of illustrations, a list of museums where noteworthy Plains Indian collections are on exhibition, an index to the references according to tribe, and an index of the tribes according to State.

An increase of 885 letters over last year brought the total number of inquiries about the American Indians received in the Director's office during the year to 3,644. In addition, staff members received many letters of a semiofficial nature, but these were not officially recorded. Leaflets and other printed materials were sent in answer to many of the inquiries, while information was supplied to others by staff members. More than 13,000 informational items, including printed and typescript articles, bibliographies, and several hundred photographic lists, were sent out in response to requests for such materials. Numerous specimens either brought to the office or sent by mail were identified for owners and data supplied on them.

Respectfully submitted.

FRANK H. H. ROBERTS, JR., *Director.*

DR. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

Report on the Astrophysical Observatory

SIR: I have the honor to submit the following report on the operations of the Smithsonian Astrophysical Observatory for the fiscal year ended June 30, 1960:

The Astrophysical Observatory includes two divisions: the Division of Astrophysical Research in Cambridge, for the study of solar and other types of energy impinging on the earth, and the Division of Radiation and Organisms in Washington, for the investigation of radiation as it relates directly or indirectly to biological problems. Shops maintained in Washington, for work in metals, woods, and optical electronics, prepare special equipment for both divisions, and a shop in Cambridge provides high-precision mechanical work. The field station at Table Mountain, Calif., carries out solar observations. Twelve satellite-tracking stations are in operation, in Florida, Hawaii, and New Mexico in the United States, and abroad in Argentina, Australia, Curaçao, India, Iran, Japan, Peru, South Africa, and Spain.

DIVISION OF ASTROPHYSICAL RESEARCH

The Observatory research staff made significant contributions to our knowledge of solar astrophysics, the upper atmosphere, meteors, meteorites, artificial satellites, and space science. The continued refinement of observational techniques and the development of new methods provided valuable data and opened up new areas of astrophysical investigation.

The Observatory continued its close liaison with Harvard College Observatory, the Massachusetts Institute of Technology, and other research centers, with mutual benefit.

Solar astrophysics.—At the Table Mountain station Alfred G. Froiland, using the atmospheric transmission coefficients obtained by Smithsonian work, made gratifying progress in his measurement of the quantity of ozone in the atmosphere and its effects in energizing the upper atmosphere. He is also studying the possibility of measuring the quantity and quality of haze. The availability of a datatron at the California Institute of Technology has broadened and simplified the scope of the investigation. A more precise and consistent method of measurement is resulting.

Dr. Max Krook, continuing his theoretical work, devised a new and more powerful method for determining the structure of nongray

atmospheres. Computation by this new procedure of a number of model atmospheres has begun, with the collaboration of Dr. Charles A. Whitney. Dr. Krook continues his investigation of various problems related to the dynamics of ionized gases, the structure of shock fronts in the presence of magnetic fields, and the kinetic theory of gases.

Dr. Whitney continued his study of stellar atmospheres, begun in 1956. Under his supervision, work on the theory of the formation of spectral lines in moving atmospheres is virtually completed. With numerical techniques developed for use with electronic computers, he is constructing first approximations to precise models of stellar atmospheres, and making preliminary calculations concerning their dynamic behavior.

Dr. Robert J. Davis completed a study of the spiral structure of the Milky Way, and the relationship between neutral hydrogen and stellar clusters and associations, by means of the 21-centimeter radiation of neutral hydrogen. His observations confirm the fact that the spiral arms are trailing and indicate that neutral hydrogen is probably concentrated in some stellar aggregates. This work makes a major contribution to our knowledge of galactic structure, and to the study of the dynamics, origin and evolution of stars, stellar clusters, associations, and the galaxy.

Dr. J. Allen Hynek is compiling a revised catalog of stars with composite spectra. In collaboration with Dr. Werner Kirschoff, using the 74-inch reflecting telescope of the Radcliffe Observatory at Pretoria, South Africa, he has obtained a series of 25 spectrograms of a number of stars with composite spectra visible only in the skies of the Southern Hemisphere to add to the catalog.

Dr. Richard E. McCrosky, in collaboration with Dr. William Sinton of the Lowell Observatory, has begun attempts to detect infrared radiation from molecular hydrogen in interstellar space, by use of infrared-sensitive detectors on the 42-inch telescope at the Lowell Observatory.

Dr. Paul W. Hodge began a study to determine the chemical composition, physical characteristics, ages, and distances of selected nearby galaxies. The work requires exceedingly detailed and accurate photometry of individual stars in the field and in clusters of certain extragalactic nebulae, and will provide evidence on the true distance scale of the universe.

Upper atmosphere.—Dr. Luigi G. Jacchia continued his study of the earth's upper atmosphere, based on analyses of the motion of artificial satellites. This work, at the very frontier of knowledge, has revealed startling new facts concerning solar-terrestrial relationships.

Dr. Jacchia has shown that at heights above 200 kilometers the density of the atmosphere displays a diurnal variation. As the earth

rotates, the atmosphere of the bright hemisphere, directly subject to solar radiation, exhibits a pronounced bulge, while that of the night hemisphere cools and contracts. In addition, the density of the entire atmosphere above 200 kilometers fluctuates in response to variations in the 20-cm solar flux, and undergoes transient, relatively rare variations caused by great storms on the sun. Dr. Jacchia has constructed a model atmosphere that accounts for these periodic fluctuations, and has developed a formula that yields the profile of atmospheric density above any point of the earth at any time, given the position of the sun and the value of the 20-cm solar flux.

This work has obvious practical application to geophysics and to space science, and the U.S. Air Force is now partially supporting an expanded program of research.

Dr. Hynek and George J. Nielson continued their balloon experiments in cooperation with the U.S. Air Force, Office of Scientific Research in Washington, D.C., Air Force Cambridge Research Center, and the Massachusetts Institute of Technology Instrumentation Laboratories. They now have scheduled unmanned balloon flights in the late summer, 1960, and plan manned balloon flights at 90,000 feet altitude in the fall of 1960. These flights are designed to determine the amount of image distortion produced by the atmosphere at altitudes between 50,000 and 100,000 feet and to study the use of infrared techniques in stellar photography, and the feasibility of instrumenting and manning astronomical observatories in high-altitude vehicles.

Dr. Hynek and George G. Barton are investigating the possible application of electronic image-converter techniques to astronomy. The preliminary system tests have been completed, and a program begun with the 20-inch Cassegrain telescope at Mount Palomar Observatory will permit comparison of observations made with image orthicon techniques with those made by current photographic techniques.

Dr. A. V. Baez devised a method of obtaining high resolution photographs with short wavelengths diffracted and focused by specially constructed Fresnel zone plates. He has also developed a reflecting X-ray "telescope" constructed of an array of crossed plane mirrors which simulate a matrix of collimated pinholes brought to a common focus. He is now working on an advanced version of this device which will use curved instead of plane mirrors. These devices will eventually produce an X-ray telescope for observations in the extreme ultraviolet and soft X-ray regions above the earth's atmosphere.

The Director and Dr. Davis continued the development of a telescope for use in space, the "Celescope." Specifications for the various components were completed, and the contract was awarded to

the Aircraft Armaments Corporation, Cockeysville, Md. Preliminary experiments are expected to be launched in an Aerobee-hi rocket early in 1961, and the satellite should orbit in 1962.

This project is of prime importance for the study of stellar and interstellar radiation in the far ultraviolet and soft X-ray regions of the spectrum. It should provide spectrograms, and television pictures, at three wavelengths, of the entire celestial sphere.

Meteoritical studies.—To stimulate interest in essential earth-based meteoritical research, the Director has outlined the most important meteoritical investigations to be carried out in the United States during the next few years, and has evaluated their importance, in a report to the National Academy of Sciences. As President of Subcommittee 22 of the International Astronomical Union, he is preparing a report on world-wide meteoritical research.

The Director and Dr. Jacchia completed an analysis of the orbits of 413 meteors photographed simultaneously by two stations with the Super-Schmidt meteor cameras to determine the physical nature of meteors and the distribution of their orbits in space. This work represents the largest amount of precise data yet obtained on meteor orbits and is vital to an understanding of the origin of meteors, their possible interaction with space vehicles, and the nature of comets and the zodiacal light. Analysis indicates that more than 98 percent of all photographic meteors have a fragile structure, are of cometary origin, and are members of the solar system. There is no evidence for an interstellar source for meteors.

In a further analysis of this large amount of photographic material, Dr. Jacchia is studying individual meteors to improve the theory of meteors and to obtain more information on meteor phenomena such as the fragmentation process and coma formation.

Continuing his study of comets, the Director is carrying out theoretical work on the structure of the cometary nucleus, and has nearly completed calculations relating to the distribution of lifetimes of long-period comets. He has derived a law for the frequency distribution of cometary lifetimes. This work contributes significantly to our understanding of the nature and evolution of comets and meteors.

Dr. E. L. Fireman, Dr. Hodge, Dr. Frances W. Wright, Dr. G. Kistner, Hai Chin Rhee, and Kenneth Covey continued the analysis of stratospheric dust collected at high altitudes by aircraft, balloons, and rockets, to determine the nature and quantity of interplanetary matter accreted by the earth. Preliminary results indicate that at heights above 50,000 feet the amount of terrestrial dust is greater than had been supposed, and that the influx of meteoritic particles into the earth's atmosphere is smaller than had been expected. Mi-

chrometeoritic dust particles have been chemically analyzed and their composition compared with that of small magnetic particles collected in the vicinity of the Canyon Diablo and Sikhote-Alin meteoritic craters. This research contributes to our understanding of the interplanetary medium.

The electron-probe microanalyzer designed and developed by Dr. F. Behn Riggs, Jr., allows the chemical analysis of a meteorite specimen without destruction of the sample. It is being used to measure the concentrations of iron, nickel, and cobalt in magnetic particles that are assumed to be micrometeorites, ranging in diameter from 50 to 1,000 microns. Particles of similar appearance are found to show a wide range of chemical content. Nickel concentrations up to 5 percent have been found in most of the particles analyzed. This research will provide more information on the history and mode of formation of meteorites.

Dr. Riggs designed and built a simple, hand-operated, scanning spectrometer which makes it possible to measure the elements in the surface of a sample more rapidly than with fixed-channel spectrometers.

Jerald P. Annese, with Dr. D. W. Batteau (formerly at Harvard University), designed and developed an emission-current regulating system for the electron-probe microanalyzer, which increases the accuracy of the analyzer.

Dr. Fireman is continuing his measurement of radioactive isotopes in meteorites. The resulting data provide basic information on the distribution, intensity, and constancy of cosmic rays in space, and indicate the probable age and original mass of specific meteorites found on earth. The time of solidification and the composition of the primordial gas in meteorites are important problems in the history of the solar system. By radiochemical methods, Dr. Fireman completed the measurements on the Aroos and Bruderheim meteorites, and has derived an estimate of the potassium-argon age of the Canyon Diablo meteorite. To increase the value of these techniques, Dr. Fireman has urged the establishment of a large-scale program for the discovery of freshly fallen meteorites.

Dr. Richard E. McCrosky began plans for implementing such a program, to locate and recover meteorites as soon as possible after their fall, by photographing meteors in flight and analyzing the photographic records to find the place of fall. The program will also augment our knowledge of the numbers, masses, and orbits of meteors.

In collaboration with scientists of the Harvard College Observatory, the U.S. Air Force, the Lincoln Laboratories of the Massachusetts Institute of Technology, and the New Mexico College of Agriculture

and Mechanic Arts, Dr. McCrosky began experiments with artificial meteors. Plans include the injection into the atmosphere, at meteoric velocities, of bodies of sufficient and known size to reproduce the meteor phenomenon. The work should help calibrate the mass-luminosity scale of natural meteors.

Dr. McCrosky, in collaboration with Mrs. Annette Posen, completed a program begun at Harvard College Observatory to determine the distribution of meteoric material in the solar system, and its correlation with comets. The analysis of the orbits of some 2,500 photographic meteors strongly suggested new correlations between the orbits of comets in general and those of meteors in general.

Satellite-tracking program.—The network of 12 satellite-tracking camera stations, under the supervision of the Director, assisted by Jack Slowey, astronomer, John Grady, operations officer, and J. Aubrey Stinnett, engineer, supplied to the Cambridge headquarters some 13,000 photographs of the artificial satellites. Refined techniques have made possible the better alignment of camera with satellite. Using the Henize-Moore tracking tables, Mr. Grady developed techniques by which the camera can track a satellite for 5,000 miles of its passage, almost 30 minutes of continuous photography. In August 1959, the camera at the station at Woomera, Australia, successfully photographed the Satellite 1959 82 (Explorer VI) at a distance of 14,000 miles.

The Moonwatch program continued under the supervision of Leon Campbell, Jr. Moonwatch teams have now transmitted more than 16,000 observations to Cambridge headquarters. These constitute basic data for correcting ephemerides and for acquiring and re-acquiring non-broadcasting satellites. During the year, Moonwatch teams were able to relocate the "lost" Satellite 1958 Epsilon. Their observations made valuable contributions to studies of the Russian Sputnik III and the many pieces into which it disintegrated upon the separation of the "chamber" from the rocket assembly. Moonwatch now comprises 137 teams in various parts of the world.

Under the supervision of Dr. Karoly Lassovszky, the Photo-reduction Center in Cambridge processed the 13,000 films received from the tracking stations; 8,705 contained images suitable for preliminary field determinations of satellite position, and of these some 3,700 images were found suitable for precise measurement and analysis.

Under the supervision of Dr. Whitney, the Research and Analysis Division in Cambridge continued to derive precise orbits from optical and radio data. The Differential Orbit Improvement program devised by Dr. George Veis proved highly valuable for this work.

Space science.—Dr. Whitney made a detailed theoretical study of the tumbling of Explorer IV by numerical integration of the gravitational forces on the satellite. He also carried out theoretical studies of the thermal balance and nighttime cooling of the ionosphere.

Dr. Yoshihide Kozai investigated the effects of solar radiation on the motion of earth satellites, and derived general mathematical expressions for the variations of orbital elements of a close earth satellite moving under the gravitational field of the earth. He has derived numerical values for the amplitudes of the second, third, fourth, and fifth harmonics of the earth's gravity field and has begun work to derive the coefficients of the tesseral harmonics.

Dr. Don A. Lautman completed work on the determination of the orbit of Satellite 1958 Epsilon during the lifetime of its telemetry and during its entire lifetime; the orbit is more precise by an order of magnitude than previous orbits. He has also found the effects on the orbit of the third harmonic in the earth's potential.

Imre G. Izsak is developing a method of orbit determination from simultaneous Doppler-shift measurements from three photographic tracking stations. With this method good orbits can be determined from a single passage, regardless of the weather. From Baker-Nunn and radio data, he determined definitive elements for an 80-day period in the lifetime of Satellite 1958 Gamma (Explorer III). By application of Jacobi's elliptic functions, Mr. Izsak seeks to obtain a solution to Vinti's dynamical problem, which is closely related to the perturbations caused by the earth's flattening.

Rajendra C. Nigam has studied the orbits of Satellites 1959 $\alpha 1$ and $\alpha 2$. He has also completed a reanalysis of the orbit of Satellite 1958 Zeta; this work has particular value because of the short lifetime and low elevation of the satellite.

Dr. Pedro E. Zadunaisky began an analysis to determine the orientation of satellites by comparing the drag perturbations on nonspherical satellites with those on spherical satellites. This work will amplify our knowledge of atmospheric densities and the motion of a satellite around its center of gravity.

The measurement of the earth's albedo and a study of its possible correlation with meteorological phenomena have continued under the supervision of Dr. Gustav A. Bakos. An analysis of results obtained in 1958 has begun.

The Communications Center, under the supervision of Charles M. Peterson, continues to clear an average of 500,000 words per month. About 90 percent of the messages sent and received contained satellite observations, predictions, and orbital elements.

At two joint communications meetings held by the Smithsonian Astrophysical Observatory, the National Aeronautics and Space Administration, and the National Space Surveillance Control, steps were taken to eliminate duplication of transmission of satellite information. Teletype distribution lists were exchanged and areas of responsibility were determined.

PUBLICATIONS

Publications of the Smithsonian Contributions to Astrophysics included numbers 6 through 9 of volume 3, number 1 of volume 4, and numbers 1 to 3 of volume 5. The following papers by staff members of the Astrophysical Observatory appeared in various journals:

- BAEZ, A. V. Graphical derivation of the inverse square law of gravitation from an elliptical orbit and Kepler's law of areas. *Amer. Journ. Phys.*, vol. 28, p. 254, 1960.
- BAKOS, G. A. The color-magnitude diagram of visual binaries (abstract). *Astron. Journ.*, vol. 64, pp. 323-324, 1959.
- FECHTIG, H., GENTNER, W., and KISTNER, G. Räumliche Verteilung der Edelgasisotope im Eisenmeteoriten Treysa. *Geochim. et Cosmochim. Acta*, vol. 18, pp. 72-80, 1960.
- FIREMAN, E. L. A program for collecting meteorites. *Science*, vol. 131, pp. 1824-1831, 1960.
- FIREMAN, E. L., and DEFELICE, J. Argon-39 and tritium in meteorites. *Geochim. et Cosmochim. Acta*, vol. 18, pp. 183-192, 1960.
- . Argon radioactivity in a recently fallen meteorite—a deep-space probe for cosmic rays (abstract). *Trans. Amer. Geophys. Union*, vol. 41, p. 337.
- HYNEK, J. A. Occultation of the bright star Regulus by Venus. *Science*, vol. 130, pp. 707-709, 1959.
- HYNEK, J. A., and STANGER, P. C. The composite-spectrum star 5 Lacertae. *Publ. Astron. Soc. Pacific*, vol. 71, pp. 310-315, 1959.
- JACCHIA, L. G. Corpuscular radiation and the secular acceleration of satellites (abstract). *Astron. Journ.*, vol. 64, p. 335, 1959.
- . Individual characteristics of meteor families (abstract). *Astron. Journ.*, vol. 65, p. 53, 1960.
- . Letter to editor. *Sky and Telescope*, vol. 19, p. 473, 1960.
- KOZAI, Y. On the motion of a close earth satellite (abstract). *Astron. Journ.*, vol. 64, p. 337, 1959.
- . The motion of a close earth satellite. *Astron. Journ.*, vol. 64, pp. 367-377, 1959.
- KROOK, M. Shock fronts in ionized gases. *Ann. Phys.*, vol. 6, p. 188, 1959.
- . Structure of stellar atmospheres. III. *Astrophys. Journ.*, vol. 130, pp. 286-295, 1959.
- . Continuum equations in the dynamics of rarefied gases. *Journ. Fluid Mechanics*, vol. 6, pp. 523-541, 1959.
- STERNE, T. E. Effect of the rotation of a planetary atmosphere upon the orbit of a close satellite. *Journ. Amer. Rocket Soc.*, vol. 29, pp. 777-782, 1959.
- VEIS, G. Geodetic uses of artificial satellites. *Smithsonian Contr. Astrophys.*, vol. 3, 95-161, 1960.
- WHIPPLE, F. L. Solid particles in the solar system. *Journ. Geophys. Res.*, vol. 64, pp. 1653-1654, 1959.
- . Fundamental problems in predicting positions of artificial satellites. *Proc. Symp. Applied Math.*, vol. 9, pp. 36-47, 1959.

WHIPPLE, F. L. Meteoritic material in space. In "Physics and Medicine of the Atmosphere and Space," edited by O. O. Benson, Jr., and H. Strughold, pp. 48-59, 1960.

———. Sub-commission 22a, Report on meteorites. Trans. Intern. Astr. Union, vol. 10, pp. 345-353, 1960.

———. Notes on the immediate feasibility of an orbiting astronomical telescope. IX International Astronautical Congress, 1958, Springer Verlag, pp. 92-95.

WHIPPLE, F. L., and DAVIS, R. J. Proposed stellar and interstellar survey. Astron. Journ., vol. 65, pp. 285-290, 1960.

WHITNEY, C. A. Stellar Thermopauses. Mem. Soc. Roy. Sci. Liège, ser. 5, vol. 3, 1959.

WRIGHT, F. W., JACCHIA, L. G., and BOEHM, B. W. Photographic Lyrid meteors (abstract). Astron. Journ., vol. 64, p. 349, 1959.

———. Photographic Lyrid meteors. Astron. Journ., vol. 65, pp. 40-45, 1960.

The Special Reports of the Astrophysical Observatory distribute catalogs of satellite observations, orbital data, and preliminary results of data analysis prior to journal publication. Nos. 28 through 44, issued during the year, contain the following material:

Special Report No. 28, Sept. 16, 1959.

Catalogue of satellite observations for May and June, 1959, by R. G. Albert.

The orbits of Satellites 1958 Alpha, 1958 β 1, 1958 β 2, 1958 δ 2, 1959 α 1, 1959 α 2, by G. Veis.

Special Report No. 29, Sept. 21, 1959.

Solar effects on the acceleration of artificial satellites, by L. G. Jacchia.

Special Report No. 30, Nov. 12, 1959.

Anticipated orbital perturbations of Satellite 1959 δ 2, by Y. Kozai and C. A. Whitney.

A table of the times of perigee passage for Satellite 1958 β 2, by R. E. Briggs.

Note on the secular motions of the node and perigee of an artificial satellite, by Y. Kozai.

Special Report No. 31, Jan. 18, 1960.

Catalogue of observations of Satellites 1958 α 1, 1958 β 1, and 1958 β 2, for July and August, 1959, prepared by R. G. Albert. Osculating elements, by Y. Kozai.

Special Report No. 32, Jan. 29, 1960.

Catalogue of observations of Satellite 1958 δ 2 for July, 1959, prepared by R. G. Albert.

Special Report No. 33, Feb. 1, 1960.

On the effects of image motion on the accuracy of measurement of a flashing satellite, by J. A. Hynek.

Special Report No. 34 (C-8), Feb. 2, 1960.

Catalogue of observations of Satellite 1958 δ 2 for the period through Aug. 22, 1959, prepared by R. G. Albert.

Special Report No. 35 (C-9), Feb. 5, 1960.

Catalogue of observations of Satellite 1958 δ 2 for the period Aug. 23 through Aug. 31, 1959, prepared by R. G. Albert.

Special Report No. 36 (C-10), Feb. 8, 1960.

Catalogue of additional observations of Satellite δ 2 for the period from May 1 through May 29, 1959, prepared by R. G. Albert.

Special Report No. 37 (C-11), Feb. 10, 1960.

Catalogue of observations of Satellites 1958 δ 2, 1958 Epsilon, and 1958 Zeta, prepared by R. G. Albert.

Special Report No. 38, Jan. 15, 1960.

Orbit determination from simultaneous Doppler-shift measurements, by I. G. Izsak.

Special Report No. 39, March 30, 1960.

A variable atmospheric-density model from satellite accelerations, by L. G. Jacchia.

Special Report No. 40, May 24, 1960.

Orbital elements for July and August, 1959, for Satellite 1958 Alpha, by B. Miller; for Satellite 1958 β 1, by C. A. Martin; for Satellite 1958 δ 2, by Y. Kozal; for Satellites, 1959 α 1 and α 2, by R. C. Nigam; for Satellite 1958 Gamma, by I. G. Izsak.

Relative positions of the sun and perigee of an artificial earth satellite, by P. E. Zadunaisky.

Special Report No. 41, May 24, 1960.

The catalogue of precise satellite positions, by K. Lassovszky.

Preliminary time reduction for the determination of precise satellite positions, by E. Weston.

The star chart project, by P. A. Pardue.

Explanation of codes used in the catalogue, by E. P. Bullis.

Shutter correction in time for the Baker-Nunn camera, by P. E. Zadunaisky.

Special Report No. 42 (C-12), May 24, 1960.

Catalogue of satellite observations for the period Sept. 1 through Dec. 31, 1959, prepared by D. V. Mechau.

Special Report No. 43 (C-13), May 25, 1960.

Catalogue of satellite observations for the period July 1 through Dec. 31, 1959, prepared by D. V. Mechau.

Special Report No. 44 (C-14), May 25, 1960.

Catalogue of satellite observations, prepared by D. V. Mechau.

OTHER ACTIVITIES

Members of the staff presented papers at meetings of the American Astronomical Society, the American Physical Society, the American Geophysical Union, the National Telemetering Conference, the American Meteorological Society, the American Astronautical Society, the American Philosophical Society, the Optical Society of America, the International Association of Geodesy, the Institute of Aeronautical Sciences, and the National Aeronautics and Space Administration.

The Director and Dr. Jacchia presented papers to the Institute of Aeronautical Sciences in New York. Dr. Krook participated in the International Symposium on Fluid Dynamics of the Ionosphere held at Cornell University. Dr. Hynek led the Astrophysical Observatory's expedition to Spain to observe the occultation of the star Regulus by the planet Venus. George J. Nielson led an airborne expedition to observe the solar eclipse of October, 1960. Dr. Lantman attended a conference of the Geodesy Committee of the Space Science Board of the National Academy of Sciences. He also represented the Smithsonian Institution at the First Interspace Science Symposium held in Nice, January 9-15, 1960. Dr. Whitney presented a paper at the Advanced Research Projects Agency symposium in

Florida, and at the International Symposium on Astrophysics, Liège, Belgium. Dr. Whitney, Carl W. Tillinghast and Charles E. Moore attended a symposium on orbital computation held at the Jet Propulsion Laboratory of the University of California Institute of Technology. In March, the Director attended the meetings of the Panel on Science and Technology with the Committee on Science and Astronautics, held at the House of Representatives in Washington. Dr. Bakos attended the General Assembly of the Royal Astronomical Society of Canada. Mr. Peterson attended a joint conference held by the Smithsonian Institution, the National Aeronautics and Space Administration, and the National Space Surveillance Control, in Washington, May 15 to 21, 1960. Dr. Hodge was present at the meetings of the American Association for the Advancement of Science and the Astronomical Society of the Pacific held concurrently in Oregon, June 13-15, 1960. Dr. Fireman attended a special meeting of the National Academy of Sciences held in Highland Park, Ill., June 19-22, 1960.

CHANGES IN STAFF

Dr. Theodore E. Sterne accepted a position at the Johns Hopkins University, Office of Operations Research. He left the Observatory during the summer of 1959.

Dr. Karl G. Henize resigned to join the staff of the Dearborn Observatory, Northwestern University.

Dr. J. Allen Hynek accepted the position of Head of the Department of Astronomy and Director of the Dearborn Observatory, Northwestern University, and will leave the Observatory in the summer of 1960.

As of June 30, 1960, 265 persons were employed at the Observatory.

BUILDINGS AND EQUIPMENT

The Astrophysical Observatory occupies space in six separate leased buildings. Construction of Harvard University's new Space Science Building on the grounds of the Harvard College Observatory has advanced rapidly, and it is expected that Astrophysical Observatory offices will occupy the building under lease in December 1960.

DIVISION OF RADIATION AND ORGANISMS

The Division continued its research in the field of photobiology, using the techniques of biochemistry, biophysics, and plant physiology. Particular emphasis was placed on understanding the cellular and subcellular mechanisms involved in photomorphogenesis and phototropism and how these responses are mediated by radiant energy.

Oxidative phosphorylation is the process by which energy is made available for growth of etiolated plant tissue. Investigations were

undertaken to determine the effects of radiant energy on this system by assaying for high-energy phosphate after treatment with red and far-red energy. The adenosine triphosphate (ATP) content was assayed utilizing a luciferin-luciferase method, and the nucleotide phosphate by absorption on activated charcoal and by the uptake of radioactive phosphorus. Red, far-red irradiation did not significantly alter the ATP level in hypocotyl hook tissue, but the light treatment produced a marked photomorphogenic response as compared to dark controls. When growth of bean hypocotyls was inhibited 40 percent by dinutrophenol, the ATP level was also found to be reduced by the same amount. Thus, it is indicated, although over-all growth response is dependent on ATP, the ATP alone is not the controlling factor in influencing photomorphogenic responses.

The effect of inhibitors of protein synthesis on chlorophyll formation and the relationship of protein synthesis to the red, far-red regulation of photomorphogenesis have been studied. Previous work with bean plants has shown that, after the initial conversion of protochlorophyll to chlorophyll, the rate of chlorophyll synthesis does not reach a maximum until after at least 4 hours of continuous irradiation. This lag period can be considerably shortened if leaves are irradiated briefly and incubated overnight in the dark before being subjected to continuous irradiation. Chloramphenicol has been found to abolish the stimulatory effect of light pretreatment. Unlike nontreated leaves, chloramphenicol-treated leaves do not show an increase in rate of chlorophyll synthesis upon extended continuous irradiation. P-fluorophenylalanine and 6-azauracil appear to affect chlorophyll synthesis similarly.

Although chloramphenicol inhibits the light-induced increase in the capacity to synthesize chlorophyll, other photomorphogenic responses of the bean plant apparently are not inhibited. Leaves irradiated in the presence of chloramphenicol accumulate considerable quantities of chlorophyll. Nevertheless, they have not the capacity to photosynthesize. Chloramphenicol does not affect the photosynthetic ability of leaves greened in its absence. It has been confirmed that radiant energy (700–1100 $m\mu$) which is not effective in promoting chlorophyll formation can induce the formation of the photosynthetic enzyme, TPN-linked glyceraldehyde-3-phosphate dehydrogenase. Another photosynthetic enzyme, photosynthetic pyridine nucleotide reductase, seems to be similarly affected.

Previous studies indicated that the lag phase of chlorophyll synthesis could be lengthened by irradiation with X-rays of 5 to 10 kiloroentgens and that subsequent exposure to 10 minutes of white light initiated recovery of the chlorophyll-synthesizing mecha-

nism. A similarity of response between exposure to X-rays and gamma rays has been established, as well as a similarity of response by monocotyledonous and dicotyledonous leaf tissue. A maximal effect on chlorophyll synthesis lag phase is obtained with dosages of 14 kiloroentgens. Experiments in which fresh sucrose solution is supplied to the tissues subsequent to the X-irradiation indicated that X-rays do not affect chlorophyll synthesis by means of their action on carbohydrate substrates. Results of exposure to red or blue broad band radiation indicate that red is effective to a greater degree than blue. These data imply that there is not a reversal of ionizing radiation effects, but rather a photomorphogenic response superimposed on the damaging effects of X-irradiation.

Action spectra of the light-induced and light-inhibited germination of seeds of *Arabidopsis thaliana* have been completed. Except for a slight shift of about 10 $m\mu$ toward longer wavelengths of the reversal action spectrum, the action spectra correspond to those determined previously for the bean hypocotyl hook. The action spectrum for germination has a broad maximum at 660 $m\mu$ with decreased sensitivity extending through 400 $m\mu$. On the long wavelength side, there is a sharp drop to the isobestic point at 690 $m\mu$. The action spectrum of reversal has a sharp maximum at 720 $m\mu$ and a secondary peak at 740 $m\mu$, with little or no activity beyond 780 $m\mu$.

The effects of polarized light on the phototropic and light-growth responses of *Phycomyces* sporangiophores immersed in paraffin oil have been investigated in order to determine whether the photoreceptors in *Phycomyces* are oriented or nonoriented. The effects obtained in paraffin oil are not definitive and the data could fit either possibility. In order to resolve this question, measurements must be made in an immersion fluid which has an index of refraction between 1.6 and 1.7. Numerous such media have been tested, but all have proved toxic to the sporangiophores.

Three new members were added to the research staff of the Division: Dr. Lars Loercher, plant physiologist; Dr. Richard L. Latterell, cytogeneticist; and John L. Edwards, plant physiologist. Dr. Loercher and Mr. Edwards came to the Division from the Agricultural and Mechanical College of Texas, where they were working on photomorphogenic responses as affected by photomimetic substances. Dr. Latterell comes from the Brookhaven National Laboratory, where he was engaged in genetic studies.

The installation of the radioisotope laboratory and counting room was completed, and these are in current use. The greenhouse is in operation, and the control rooms are nearing completion and should be ready for use in the research program by the fall of 1960.

PUBLICATIONS

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- WITHROW, ROBERT B. A kinetic analysis of photoperiodism. In "Photoperiodism and Related Phenomena in Plants and Animals." Amer. Assoc. Adv. Sci. Publ. 55, pp. 439-471, 1959.
- WOLFF, JOHN B., and PRICE, LEONARD. The effect of sugars on chlorophyll biosynthesis in higher plants. Journ. Biol. Chem., vol. 235, pp. 1603-1608, 1960.

OTHER ACTIVITIES

Dr. W. H. Klein and Dr. W. Shropshire participated in the International Botanical Congress in Montreal, where Dr. Shropshire presented a paper, "Action Spectra of the Light-growth and Tropic Responses of Phycomyces," and Dr. Klein participated in the executive committee sessions of the American Society of Plant Physiologists. Dr. Klein also attended the International Symposium on Growth and Development at Purdue University, and Dr. Shropshire attended the Fourth Annual Meeting of the Biophysical Society at Philadelphia and a symposium at the Johns Hopkins University in Baltimore on the subject "Light and Life."

Dr. E. Sisler, Dr. M. Margulies, L. Price, and V. Elstad attended the meetings of the American Institute of Biological Sciences at Pennsylvania State University, and Drs. Sisler and Margulies attended the annual meetings of the Federation of American Societies for Experimental Biology in Chicago.

Respectfully submitted.

FRED L. WHIPPLE, *Director.*

DR. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

Report on the National Collection of Fine Arts

SIR: I have the honor to submit the following report on the activities of the National Collection of Fine Arts for the fiscal year ended June 30, 1960.

SMITHSONIAN ART COMMISSION

The 37th annual meeting of the Smithsonian Art Commission was held in Washington on Tuesday, December 1, 1959. Members present were Paul Manship, chairman; Robert Woods Bliss, vice chairman; Leonard Carmichael, secretary; Gilmore D. Clarke, David E. Finley, Lloyd Goodrich, Walker Hancock, Bartlett H. Hayes, Jr., Ogden M. Pleissner, Charles H. Sawyer, Stow Wengeroth, and Andrew Wyeth. James C. Bradley, Assistant to the Secretary of the Smithsonian Institution, and Thomas M. Beggs, Director, National Collection of Fine Arts, were also present.

The Commission recommended reappointment of Lloyd Goodrich, Walker Hancock, Bartlett H. Hayes, Jr., and Douglas W. Orr for the usual 4-year period.

The following officers were reelected for the ensuing year: Paul Manship, chairman; Robert Woods Bliss, vice chairman; and Leonard Carmichael, secretary.

The following were reelected members of the executive committee for the ensuing year: David E. Finley, chairman; Robert Woods Bliss, Gilmore D. Clarke, Archibald G. Wenley, with Paul Manship and Leonard Carmichael *ex officio*.

Mr. Clarke reported that the subcommittee appointed to advise in the development of plans for housing the National Collection of Fine Arts in the Old Patent Office Building consisted of Thomas M. Beggs, Gilmore D. Clarke (chairman), Walker Hancock, Wilmarth S. Lewis, Douglas W. Orr, and Ogden M. Pleissner, with Leonard Carmichael and Paul Manship, *ex officio*. At a meeting held October 12, 1959, it was pointed out that the building might be transferred in 1963 or 1964, and would be expected to house the National Collection of Fine Arts and a national portrait collection as separate units. Following a tour of the building, it was concluded that it could be adapted to

the needs of both collections but that a survey by engineers and architects would be necessary before plans could be drawn for structural changes.

Dr. Carmichael reported that, in accordance with a resolution adopted at the 1958 Smithsonian Art Commission meeting, a committee of the Board of Regents, consisting of Dr. John Nicholas Brown, chairman, Senator J. W. Fulbright, Representative Frank T. Bow, and Dr. Caryl P. Haskins, had been appointed by the Chancellor to assist in the organization of a National Portrait Gallery and to advise in the development of plans for adapting the Old Patent Office Building to the needs of such a gallery.

The Smithsonian Institution has a collection of over 125 subjects designated, since acceptance in 1921 of the gift of 22 paintings from the National Art Committee, as a National Portrait Gallery. The National Gallery of Art has many important portraits of distinguished Americans, and other government departments have portraits appropriate for such a gallery.

The site of the Patent Office Building was prominent in L'Enfant's plan of Washington. Administrative studies were initiated preliminary to the formulation of plans for the use of the building. A study will be made before the next meeting of the Smithsonian Art Commission concerning the authorized functions of the National Collection of Fine Arts and its relationship to other Government galleries.

The Commission conveyed its greetings and hope for his early recovery to A. G. Wenley, Director of the Freer Gallery of Art.

The Commission recommended acceptance of the following objects:

Marble, Seated Nude, by Maurice Sterne (1877-1957). Offered by Lauson H. Stone, New York City (through the National Gallery of Art).

Oil, An Eclogue, by Kenyon Cox (1856-1919). Offered by Allyn Cox, New York City.

Three oil sketches to scale of a mural painting in the Iowa State Capitol by Kenyon Cox. Offered by Allyn Cox.

Two oils, Trapped in a Dungeon of Joy, by Atellio Salemmme, and Unknown Subject, by Theodoros Stamos. Offered by the Maritime Administration through the General Services Administration.

Watercolor, James Smithson (1765-1829). Transfer from the Smithsonian Institution.

Fourteen pencil drawings by Kenyon Cox. Offered by Allyn Cox.

Three etchings by Gerald K. Geerlings (1897-): Black Magic (etching and aquatint), Olympus (drypoint), and Inland Island (soft ground etching). Offered by the artist, New Canaan, Conn.

Seventeen fans added to the Pepita Milmore Collection of 18th- and 19th-century French and English fans accepted in 1956. Offered by Henry L. Milmore, Washington, D.C.

THE CATHERINE WALDEN MYER FUND

The following miniatures, watercolor on ivory, were acquired from the fund established through the bequest of the late Catherine Walden Meyer.

- No. 114. Unknown Gentleman, by Thomas Flatman (1633/7-1688).
- No. 115. John (or Uriah) Vaughan, by Christopher Greiner (-1864).
- No. 116. Robert Parker, attributed to Henry Inman (1801-1846).
- No. 117. Self Portrait, said to be by Sarah Peale (1800-1885).
- No. 118. Self Portrait, said to be by Edward Savage (1761-1817).
- No. 119. Unknown Man, by Richard M. Staigg (1820-1881).
- No. 120. Nance de Villers, by Carolyn D. Tyler.
- No. 121. Miss Mary Angell, by Carolyn D. Tyler.
- No. 122. Elizabeth Moore, by Carolyn D. Tyler.
- No. 123. Unknown Man, by Undetermined Artist.
[Nos. 114 through 123 were acquired from Mrs. Ruel P. Tolman through Edward Kemper, Washington, D.C.]
- No. 124. Joseph Enderlin, by Lulse Walther.
- No. 125. Mrs. George Willig by Lulse Walther.
[Nos. 124 and 125 were acquired from the Corcoran Gallery of Art, Washington, D.C.]
- No. 126. India Ink portrait of a lady, by Foster, from Mrs. Mabel Munson Swan, Barrington, R.I.

ART WORKS LENT AND RETURNED

<i>Institutions</i>	<i>Loans</i>	<i>Loans Returned</i>
American Federation of Arts-----	1	
Atomic Energy Commission-----	4	
Barney Neighborhood House-----		15
B'nai B'rith-----	1	1
Budget Department-----	8	8
Corcoran Gallery of Art-----	6	6
Federal Communications Commission-----	12	1
Federal Power Commission-----	4	4
General Services Administration-----	4	
George Washington University-----	1	1
Interstate Commerce Commission-----	8	7
Internal Revenue-----	4	4
Knoedler Gallery-----	1	1
Meltzer Gallery-----	23	1
Marion Koogler McNay Art Institute-----	1	1
Post Office Department-----	6	
Senate Rules Committee-----	1	1
State Department-----	7	1
District Court-----	6	
U.S. Military Court Appeals-----	2	1
U.S. Supreme Court-----	2	
White House-----	4	
Whitney Museum-----	1	
	107	53

SMITHSONIAN LENDING COLLECTION

The following 11 oils by Emile Walters were added December 1, 1959:

Haukadal, North Iceland (looking west), site of the home of Eric the Red, where Leif Ericsson was born.

Haukadal (looking east).

Hrappsey (Island Group where Eric the Red sheltered his ship prior to his first voyage to Greenland).

Glumbaer, Skaga Fjord (home of Vinland hero, Thorfinns Karlsefni, purchased after his return to Iceland from Vinland in 1006).

View from the Plains of Parliament.

Herolsness Fjord (Ikagait Mountain home of the first Viking settlement).

Early Sunshine (Eric's Fjord, southern Greenland).

Church at Hvalsejar Fjord (first Christian Church in the west).

Eric's Fjord (glacier ice in summer).

Eric's Fjord (across from Brattahild).

Hjaraqsuitt (second Viking settlement in Greenland).

An oil, Marie Huet, by Alice Pike Barney, lent September 25, 1952, to the Department of Justice, was recalled for renovation.

The following paintings were lent for varying periods:

To the Internal Revenue Service, Washington, D.C.:

April 21, 1960----- Little Rose by S. Seymour Thomas.

To the Department of State, Washington, D.C.:

March 18, 1960----- Woman with Red Hair by Albert Herter.

THE HENRY WARD RANGER FUND

The following paintings, purchased previously but not assigned, have been allocated to the institutions indicated:

<i>Title and Artist</i>	<i>Assignment</i>
213. The Crittie (Kermit Lansner, by Aaron Shikler (1922-).	Mint Museum of Art, Charlotte, N.C.
217. The Painter, Shelley Fink, by David Levine (1926-).	University of Oregon, Eugene, Oreg.

According to a provision in the Henry Ward Ranger bequest, that paintings purchased by the Council of the National Academy of Design from the fund provided by the Bequest, and assigned to American art institutions, may be claimed during the 5-year period beginning 10 years after the death of the artist represented, the following paintings were recalled for action of the Smithsonian Art Commission at its meeting December 1, 1959.

No. 2, Evening Tide, California, by William Ritschel, N.A. (1864-1949), assigned to the National Collection of Fine Arts (formerly the National Gallery of Art) was accepted to become a permanent accession.

No. 29, Smuggler's Notch, Stowe, Vermont, by Chauncey F. Ryder, N.A. (1868-1949), assigned to the Memorial Art Gallery, University of Rochester, N.Y., was accepted to become a permanent accession.

No. 52, The Enchanted Pool by William Ritschel, N.A. (1864-1949), assigned to the Minneapolis Society of Fine Arts, Minneapolis, Minn., was accepted to become a permanent accession.

The following paintings, purchased by the Council of the National Academy of Design since the last report, have been assigned as follows:

<i>Title and Artist</i>	<i>Assignment</i>
226. Blue Marine, by Henry E. Mattson, N. A. (1887-).	North Carolina Museum of Art, Raleigh, N.C.
227. Michigan Landscape, by Louis Ritman, N. A. (1889-).	Brooks Memorial Art Gallery, Memphis, Tenn.
228. Sag Harbor, by Nicolai Cikovsky (1894-).	(Assignment pending.)
229. Still Life Epilogue, by Luigi Lucioni, N. A. (1900-).	Telfair Academy of Arts and Sciences, Savannah, Ga.
230. The Bridge (watercolor), by Hardie Gramatky, N. A. (1907-).	(Assignment pending.)
231. Dead Boats, Wellfleet (watercolor), by Thomas Sgouros (1927-).	Jacksonville Art Museum, Jacksonville, Fla.
232. High September Tide (watercolor), by Norman Kenyon (1901-).	(Assignment pending.)
233. Razing the Old New York Post Office, by Ernest Fiene, N. A. (1894-).	Museum of the City of New York, New York, N.Y.

SMITHSONIAN TRAVELING EXHIBITION SERVICE

In addition to the 54 exhibits held over from previous years as indicated, 37 new shows were introduced. The total of 89 of these were circulated to 246 museums in the United States, two having been prepared for circulation abroad.

EXHIBITS CONTINUED FROM PRIOR YEARS

1955-1956: Japan I by Werner Bischof; and Chinese Ivories from the Collection of Sir Victor Sassoon.

1956-1957: Contemporary German Prints; Architectural Photograph II; Six Japanese Painters; Japan II by Werner Bischof; and The World of Edward Weston.

1957-1958: The American City in the 19th Century; Recent American Prints; Japanese Woodblock Prints; Theatrical Posters of the Gay Nineties; Birds by Emerson Tuttle; 100 Years of American Architecture; Contemporary Portuguese Architecture; National Ceramic Exhibition, Sixth Miami Annual; Fulbright Designers; Nylon Rug Designs; Religious Banners; Burmese Embroideries; Japanese Dolls; Thai Painting; The Anatomy of Nature; Photographs of Sarawak; Glimpses of Switzerland: Art in Opera II—Carmen; The Four Seasons; and Children's Paintings from Morocco.

1958-1959: Young British Painters; German Artists of Today; Recent Work by Peter Takal; Advertising in 19th Century America: The Engravings of Pieter Brueghel the Elder; Three Danish Printmakers; Great European Printmakers; Charles Fendrich—Lithographer of American Statesmen; Drawings from Latin America; Contemporary Religious Prints from the Sloniker Collection; Religious Subjects in Modern Graphic Arts; UNESCO Watercolor

Reproductions; British Artist-Craftsmen; Contemporary Finnish Rugs; Contemporary Tapestries; Contemporary Indian Crafts; Stone Rubbings from Angkor Wat; Shaker Craftmanship; the Unguarded Moment, Photographs by Erich Salomon; Children's Paintings from India; A Child Looks at the Museum; and Swiss Children's Paintings.

EXHIBITIONS INITIATED IN 1960

Paintings and Drawings

<i>Title</i>	<i>Source</i>
20th Century American Paintings-----	Edward W. Root Collection from the Munson-Williams-Proctor Institute, Utica, N.Y.
Contemporary American Watercolors and Drawings.	Do.
The Art of Seth Eastman-----	Prof. John Francis McDermott; private collectors.
Contemporary Greek Painting-----	Artists; Greek Embassy.
Early Drawings by Toulouse-Lautrec--	Albert H. Wiggin Collection; Arthur W. Heintzelman, Boston Public Library.
Watercolors and Drawings by Thomas Rowlandson.	Do.
Prints and Drawings by Jacques Villon--	Do.

Graphic Arts

American Prints Today-----	Print Council of America; Artists.
Brazilian Printmakers-----	Artists; Brazilian Embassy; Organization of American States.
Lithographs of Fantin-Latour-----	Albert H. Wiggin Collection; Arthur W. Heintzelman, Boston Public Library.
Drawings from Latin America-----	Visual Arts Section, Pan American Union; Artists; Collectors.
Arts and Cultural Centers-----	American Institute of Architects.
Bernard Raip Maybeck-----	University of California; College of Architecture; California Palace of the Legion of Honor; California Redwood Association.

Design

Enamels-----	Museum of Contemporary Crafts, N.Y.; Artists.
Eskimo Art-----	Eskimo Art, Inc., Ann Arbor, Mich.; Canadian Embassy.
Contemporary French Tapestries II---	Association des Peintres-Cortenniers de Tapisseries, Paris; l'Association Française d'Action Artistique; French Ambassador; Artists.
Greek Costumes and Embroideries-----	Benaki Museum in Athens; Greek Embassy.
Contemporary American Glass-----	Corning Museum of Glass, Corning, N.Y.

<i>Title</i>	<i>Source</i>
Story of American Glass-----	Corning Museum of Glass, Corning, N.Y.
Midwest Designer Craftsmen-----	Designers and Craftsmen; Joslyn Art Museum.
Norwegian Tapestries-----	Historical Museum, Bergen University; West Norway Museum of Applied Arts, Bergen; Rohsska Museum of Applied Arts, Goteborg, Sweden; Sandvig Collection, Folk Museum, Lillehammer; Norwegian Folk Museum, Oslo; Oslo Museum of Applied Arts, Trondheim, Thorvald Krohn-Hansen, Director; Thor Furuholmen, Oslo.

Oriental Art

Bazaar Paintings from Calcutta-----	Victoria and Albert Museum, London; Wadsworth Atheneum, Hartford, Conn.; W. G. Archer, Victoria and Albert Museum.
Gandhara Sculpture-----	Government of Pakistan; Pakistan Committee of Asia Society; Embassy of Pakistan; Consul General of Pakistan, New York City; Prof. Benjamin Rowland of Fogg Museum, Harvard University.

Folk Art

Rumanian Folk Art-----	East-West Cultural Exchange Program, Department of State; Rumanian Embassy.
Sardinian Crafts-----	Institute of Sardinian Crafts; Dr. Francesco Deriu, Museum of Sarrari; Italian Government; Embassy of Italy.

Photography

Arctic Riviera-----	Swiss Foundation for Alpine Research; Museum of Science, Boston.
Image of America I-----	Library of Congress.
Photographs of Robert Capa II-----	Magnum Photos, Inc., New York.
Outer Mongolia-----	Asia Society, New York.
Pagan-----	Asla Society, New York.
Portraits of Greatness-----	George Eastman House, Rochester, N.Y.

Children's Exhibitions

Contrasts-----	Embassy of Union of South Africa.
Paintings by Young Africans-----	San Francisco Museum of Art, Dr. Grace Morley.

INFORMATION SERVICE AND STAFF ACTIVITIES

In addition to the 15,414 requests for information received by mail and telephone, inquiries made in person at the office numbered 1,444. In all, 250 works of art were examined, 174 of this number submitted at the office, 76 examined by the Director during field trips.

Special catalogs were published for the following traveling exhibitions: Contemporary Greek Painting, Prints by Munakata, Photographs by Robert Capa, Gandhara Sculpture, The Art of Seth Eastman, Old Master Drawings, Norwegian Tapestries, Greek Costumes and Embroideries. A special catalog of Traveling Exhibitions for 1960-61 was also published.

The Director lectured on the "Treasures in the Gellatly Collection," "Pending Legislation Regarding Art," and "The Passion Story in Washington Pictures."

Mrs. Pope visited England and several European countries to consult with government officials, museum directors, and collectors concerning new displays for the Traveling Exhibition Service.

Rowland Lyon served as juror for a number of art exhibitions.

Nineteen paintings in oil on canvas from the permanent collections were cleaned and revarnished, and 28 picture frames were repaired and refinished with the assistance of Buildings Management Service. New frames were constructed and finished for seventeen etchings. An oil, Thomas Watt Gregory of Texas, was cleaned and revarnished for the Department of Justice.

Two oil paintings, The Three Trees by William Lathrop, and Fishing Boats at Gloucester by John Henry Twachtman, were restored by Walter Frobos, Athens Lumber Co., Athens, Ga.

Francis Sullivan renovated three paintings, Self Portrait by Benjamin West, Portrait Group by Frank W. Wilkin, and Top of the Continent, Mt. McKinley, by Sydney Laurence.

The following paintings were relined and restored by Harold F. Cross: My Children, by Abbott H. Thayer; The Chief's Canoe, by Belmore Brown; James Pollard Espy, by Thomas Sully; Portrait of Admiral S. F. DuPont, by Daniel Huntington; The Peacock, by Abbott H. Thayer; A Reading, by Thomas Dewing; and Maine Coast, by Paul Dougherty.

SPECIAL EXHIBITIONS

Nine special exhibitions were held during the year:

October 20 through November 11, 1959. The 22d Metropolitan Art Exhibition, sponsored by the American Art League, consisting of 96 paintings and 21 sculptures. A catalog was privately printed.

December 12, 1959 through January 10, 1960. Norwegian Tapestries, sponsored by the Ambassador of Norway and Mrs. Paul Koht, and circulated by

the Smithsonian Traveling Exhibition Service, consisting of 60 tapestries and 55 objects of folk art. An illustrated catalog was privately printed.

January 17 through February 7, 1960. The 23d National Exhibition sponsored by the Society of Washington Printmakers, consisting of 158 prints. A catalog was privately printed.

February 14 through March 3, 1960. The 63d Annual National Exhibition sponsored by the Washington Water Color Club, consisting of 119 items. A catalog was privately printed.

February 13 through March 6, 1960. Three Danish Printmakers (Povl Christensen, Palle Nielsen, Sigurd Vasegaard), sponsored by the Ambassador of Denmark and Countess Knuth-Winterfeldt, and circulated by the Smithsonian Traveling Exhibition Service, consisting of 62 prints. An illustrated brochure was privately printed.

March 13 through April 3, 1960. The 20th Biennial Art Exhibition of the National League of American Pen Women, consisting of 206 items including paintings, sculpture, ceramics, illuminations and decorative arts. A catalog was privately printed.

April 9 through May 1, 1960. Greek Costumes and Embroideries, sponsored by the Ambassador of Greece and Mme. Liatis, and circulated by the Smithsonian Traveling Exhibition Service, consisting of 240 examples including 22 rare and beautiful costumes and household objects. An illustrated catalog was privately printed.

May 7 through 30, 1960. The World Premiere of the United States Air Force Art, consisting of 92 paintings. A catalog was privately printed.

June 5 through July 4. The Tennessee Salon, sponsored by the Tennessee Art League, consisting of 141 paintings and 9 sculptures.

Respectfully submitted,

THOMAS M. BEGGS, *Director.*

Dr. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

Report on the Freer Gallery of Art

SIR: I have the honor to submit the fortieth annual report on the Freer Gallery of Art, for the year ended June 30, 1960.

THE COLLECTIONS

Twenty objects were added to the collections by purchase as follows:

BRONZE

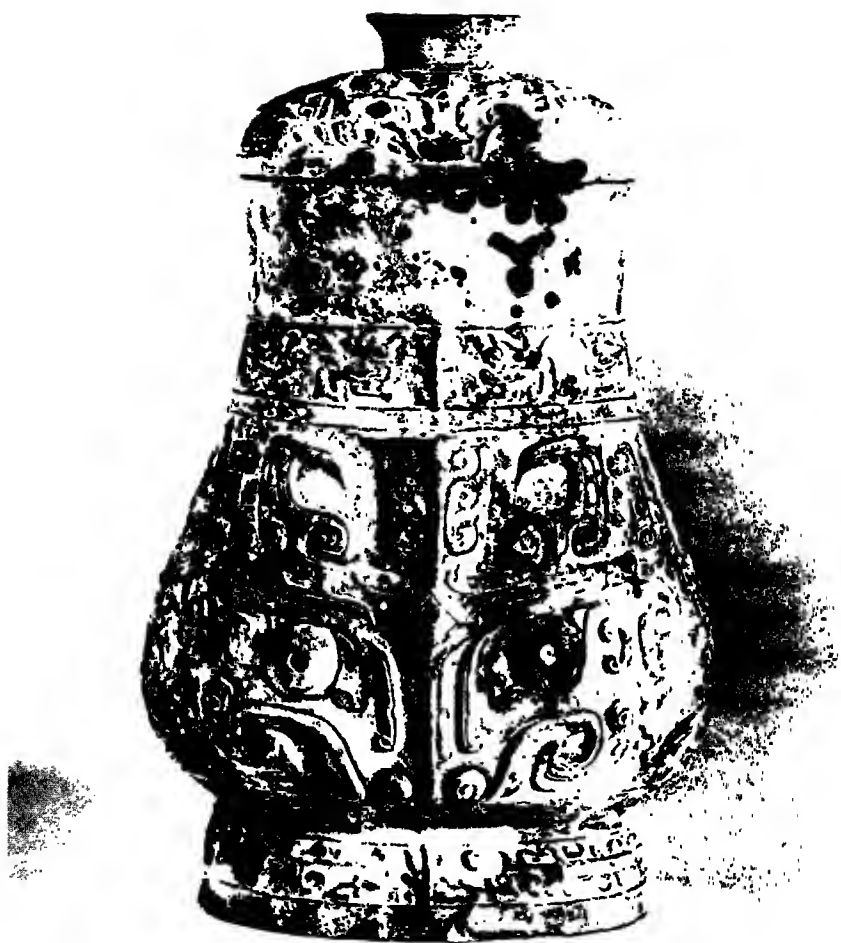
- 59.14. Chinese, Shang or early Chou, 11th century B.C. Vessel of the type *chih*. Light green patination. Design in relief. Six character inscription on both the lid and the inside bottom of the vessel. Width: 0.153, height: 0.243. (Illustrated.)
- 59.15. Chinese, Shang dynasty. Vessel of the type *ting*, with a raised nipple design on squares of something resembling the thunder pattern. These squares and the dragon band just below the lip are incised and filled with some sort of black inlay. The patina is green with traces of azurite. Inside is an inscription of four characters. Width: 0.167, height: 0.204.

LACQUER

- 60.7. Japanese, Edo period, ca. A.D. 1650. Spouted bowl with cover; wood base; of the type termed Hidehira, with Christian symbol. 0.151 x 0.235.

PAINTING

- 59.17. Chinese, dated in correspondence with A.D. 1354, Yüan dynasty, by Wang Meng. Landscape: "Secluded Dwellings in the Summer Mountains." Kakemono; ink and touches of light color on silk. One inscription and 10 seals on the painting. 0.568 x 0.342.
- 60.1. Chinese, Sung dynasty, attributed to Fan-lung, 12th century, Aihats. Nineteen seals on the painting and traces of one four-character inscription, effaced and illegible. Five colophons, accompanied by a total of 23 seals. Makimono; ink on paper. 0.305 x 10.625.
- 60.2. Chinese, Sung or Yüan dynasty, attributed to Tzu-wen (Jih-kuan), fl. mid-13th century, Grapevines. One inscription and two seals on the painting. Kakemono; ink on silk. 0.425 x 0.984.
- 60.3. Chinese, Ming dynasty, 15th or early 16th century, copy after (?) Chao Ling-jang. A pond in autumn. Eleven seals on the painting; four on the mount preceding the painting, and one on the mount following. Seven colophons, accompanied by a total of 68 seals. Makimono; colors on silk. 0.241 x 1.875.
- 60.4. Chinese, Sung dynasty, or earlier, in the style of Chou Fang. Ladies playing "double-sixes." No seals or inscriptions. Fragment of 39.37. Painted in ink and colors on silk. 0.297 x 0.154.
- 59.12. Japanese, Edo period. Ukiyoe, Miyagawa Chōsun (1682-1752). Festivals of the Twelve Months. 14.2 x 0.313.
- 59.13. Japanese, Kamakura period, Yamato-e school. Yūzū Nembutsu *Engi*, dated 1320. Makimono; ink, color and gold on paper. One of a pair: 58.11. 0.267 x 11.161.



59.14

Recent addition to the collections of the Freer Gallery of Art.



59.16
Recent addition to the collections of the Free Gallery of Art

- 59.18. Japanese, Kamakura period. 14th century, Yamato-e school. *Ippen Shōnin Eden* (fragment). Makimono; ink and color on paper. 2.058 x 0.305. (Illustrated.)
- 60.6. Japanese, Edo period. 18th century, Ōtsue. A devil playing a samisen. Ink and color on paper. 0.215 x 0.609.
- 60.8- Korean, Yi dynasty, Chong Son (Kyōmjae), 1676-1759.
- 60.12. Landscapes, five album leaves. Ink on paper. Average size: 0.145 x 0.218.

POTTERY

- 60.5. Japanese, Edo period. ca. 1650, Kutani (Suisaka). Small dish with fluted rim, of white clay with brown glaze and maple leaf decoration in white. 0.150 x 0.033.
- 59.16. Persian, 9th century, Khurasan. Deep bowl on low base, decorated with a seated figure on either side of a central tree design, space-filling birds and floral motifs. Black, yellow, and green pigments on tannish grounds, colorless glaze. Repaired. Height: 0.106. Max. diameter: 0.269. (Illustrated.)

SCULPTURE

- 59.11. Cambodian, Khmer, Angkor period, style of the Kleang (9th-10th century, A.D.). Standing figure of a female deity carved in reddish brown sandstone.

REPAIRS TO THE COLLECTION

Forty-nine Chinese and Japanese objects were restored, repaired, or remounted by T. Sugiura. In addition, he repaired one book for the library and bound 25 books for the library. Repairs to the collections outside the Freer Gallery were done by Istvan P. Pfeiffer who completed the regilding of 12 frames for paintings.

CHANGES IN EXHIBITIONS

Changes in exhibitions amounted to 468, which were as follows:

American art:		Japanese art:	
Drawings-----	29	Lacquer-----	17
Etchings-----	9	Metalwork-----	1
Lithographs-----	10	Paintings-----	91
Oils-----	37	Pottery-----	21
Water colors-----	2	Korean art:	
Chinese art:		Bronze-----	1
Bronze-----	2	Jade-----	7
Ivory-----	2	Metalwork-----	9
Paintings-----	7	Pottery-----	20
Pottery-----	3	Near Eastern art:	
Christian art:		Crystal-----	2
Crystal-----	2	Jade-----	1
Glass-----	6	Glass-----	11
Gold-----	18	Manuscripts-----	26
Manuscripts-----	8	Metalwork-----	38
Paintings-----	14	Paintings-----	20
Stone sculpture-----	2	Pottery-----	33
Indian art:		Tibetan art:	
Lacquer-----	1	Paintings-----	4
Metalwork-----	2		
Paintings-----	3		

LIBRARY

Accessions of books, pamphlets, periodicals, and study materials totaled 738 pieces of which over one-half were purchases. Unfortunately the cost of publication increases, and the many institutions and societies that formerly sent their journals freely, in exchange or gratis, now find it necessary to offer them on subscription basis in order to assure continuity of publication. Fewer titles were acquired but the cost of the purchases was greater.

Some important works acquired in a wide bibliography of art included *Hō-un*, nos. 1-36 (1932-1946), Tokyo and Kyoto; *Ku Kung min hua san pai chung* (300 masterpieces of Chinese painting in the Palace Museum collection), selected and compiled by an editorial committee . . . of the National Palace Museum and the National Central Museum, Taichung, Taiwan, 1959; six folio *pên in t'ao*; *Shanghai po-wan-kuan ts'ang-hua chi* (collection of paintings from the Shanghai Museum), Shanghai jen-min ch'u-pan-she, 1959; *Chinese painting: leading masters and principles*, by Osvald Sirén, 2 sections in 7 volumes, New York, Ronald Press, 1956-58; *Chung-hua ta tz'ü tien* (Encyclopedia sinica), compiled by Yang Chia-lo, to be complete in 40 volumes, Taipei. Chinese cultural research institute, 1960; *The Maasir-ul-umara*, by Nawáb Samsam-ud-Dowla Shah Nawáz Khan Rahím . . . Calcutta, Asiatic Society of Bengal, 1887-1897, 3 volumes in Persian; *The Māāthir-ul-umarā*, being biographies of the Muhammadan and Hindu officers of the Timurid sovereigns of India from 1500 to about 1780 A.D., by Nawwāb Samsam-ud-Daulah Shāh Nawaz Khan and his son 'Abul-Hayy (second edition), translated by H. Beveridge . . . revised, annotated, and completed by Baini Prasha, Calcutta, Royal Asiatic Society, 1911-52, 2 volumes (Bibliotheca Indica, Work No. 202); *Nishikie no kairin no kōshō* (the date proof marks on prints), by Ishii Kendō, Tokyo, Isehin shoten, 1920.

An exchange of study photographs of Whistler paintings has been instituted with the University of Glasgow, and the Gallery has received 80 study photographs of the little-known Whistler paintings which Miss Rosalind Birnie Philip gave to the University.

Sam R. Broadbent presented an etching for the study collection, "Little Quimper," by Charles A. Platt, the architect for the Freer Building.

Four locked bookcases of four sections each installed by the cabinet shop provided much-needed expansion for the Orientalia. Mrs. Hogenson and Mrs. Usilton did the reshelving and made an inventory while doing so. All the cataloged books and pamphlets were accounted for when finished. The folio books were marked with the proper symbol and the catalog cards marked to correspond.

The year's record of cataloging is current and included a total of 1,782 entries of which 1,039 were analytics, 280 books and pamphlets (by title) were cataloged, and 35 titles were recataloged and reclassified. The original and difficult nature of the cataloging is emphasized by the fact that only 8 percent of the necessary cards were found at the Library of Congress.

In all, 422 scholars and students not members of the Freer staff used the library. Twenty-two of these saw and studied the Washington Manuscripts and five interested persons came to see the library installation.

PUBLICATIONS

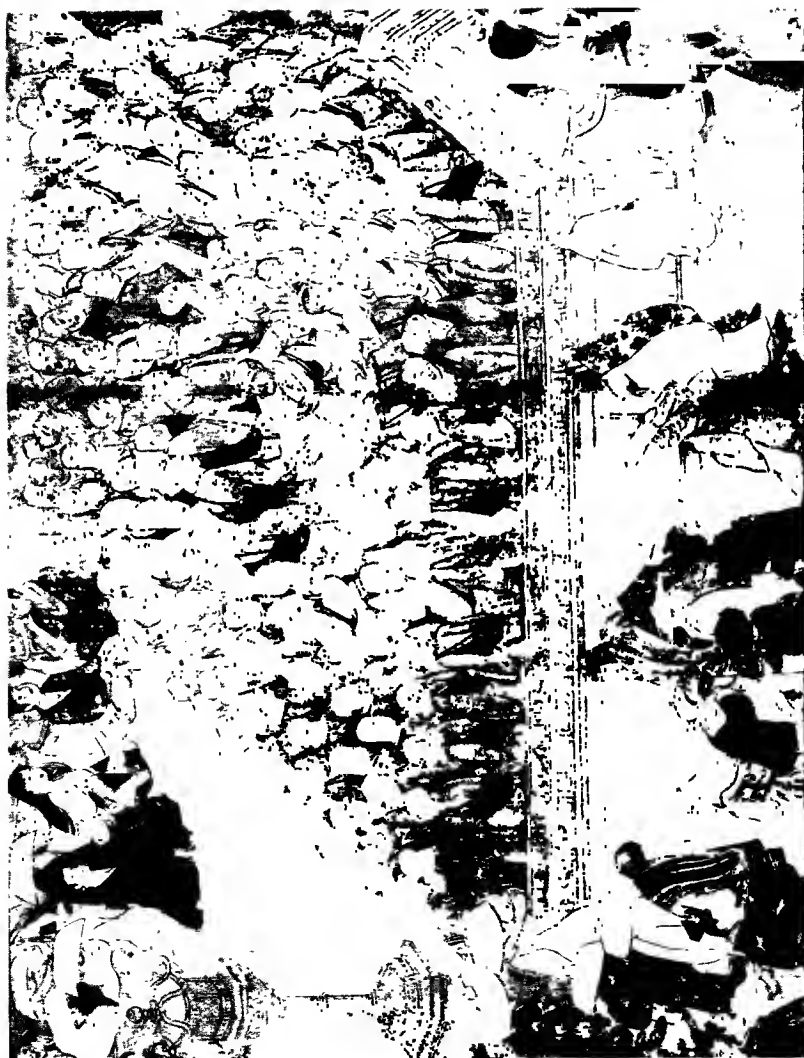
Four publications were issued by the Gallery as follows:

- Ars Orientalis*, Vol. 3, 12 articles in English, French, or German, 16 book reviews, 1 bibliography, 4 notes, In Memoriam. (Smithsonian Institution Publication 4381.) (263 pp., 137 collotype pls., text illustrations.)
- Medieval Near Eastern ceramics in the Freer Gallery of Art*, by Richard Ettinghausen. Illus. cover, 7 pp. text and 31 pp. with 40 illus. (Smithsonian Institution Publication 4420.)
- Occasional Papers*, Vol. 3, No. 2: Calligraphers and Painters, by V. Minorsky, 1959. (Smithsonian Institution Publication 4339.) (223 pp., 8 collotype pls.)
- Hokusai: Paintings and drawings in the Freer Gallery of Art*, by Harold P. Stern, illus. cover, 11 pp. text and 25 pp. with 36 illus. (Smithsonian Institution Publication 4419.)

Papers by staff members appeared in publications as follows:

- CAHILL, JAMES F. Chinese paintings, xi-xiv centuries. New York, Crown Publishers, 1960. 40 pp. illus., 27 pls. (part col.) (Art of the East library.)
- . A rejected portrait by Lo P'ing; pictorial footnote to Waley's *Yüan Mei. Asia Major*, n. s., vol. 7, pp. 32-39, 3 pls., 1959.
- . Review of "Mindai no kaiga," by Yonezawa Yoshiho Tokyo, Mayuyama Ryūsenshō, 1956. *Revue bibliographique de sinologie*, vol. 2, no. 345, 1956.
- . Review of "Rō Kan no sakuhin ni tsuite," by Rōtani Kenyū, *Bunka*, vol. 20, pp. 234-247, 1956. *Revue bibliographique de sinologie*, vol. 2, no. 342, 1956.
- . Review of "The tao of painting," by Sze Mai-mai. 2 vols., New York, Pantheon Books, 1956. *Revue bibliographique de sinologie*, vol. 2, no. 346, 1956.
- ETTINGHAUSEN, RICHARD. Abbasside art: Mural painting; miniatures; decorative arts (pottery, glass and rock crystals, woodwork, textiles). *Encyclopedia of world art*, New York, McGraw-Hill Book Co., vol. 1, cols. 10-15, pls. 4-13, 1959.
- . 'Abdu 'S-Šamad, or Hvāga, 'Abdu 'Šamad. *Encyclopedia of world art*, New York, McGraw-Hill Book Co., vol. 1, cols. 15-19, pls. 14-17, 1959.
- . Bibliography of the writings of J. V. S. Wilkinson. *Ars Orientalis*, vol. 3, pp. 259-262, 1959.
- . Bihzad, Kamal al-Dīn. *Encyclopedia of Islam*. 2d ed., Leiden, E. J. Brill; London, Luzac & Co., vol. 1, fasc. 19, pp. 1211-1214, pls. xxxiii-xxxvi, 1959.

- ETTINGHAUSEN, RICHARD. The Bustan manuscript of Sultan Nasir Shah Khalji. *Marg.*, vol. 12, No. 3, pp. 42-43, illus., June 1959.
- . Les elements decoratifs turcs des objets en or et en argent. *Papiers premier congrès international des arts turcs . . .* (Université d'Ankara), p. 89, 1959.
- . Further comments on the Wade Cup. *Ars Orientalis*, vol. 3, pp. 197-200, pl., 1959.
- . Near Eastern book covers and their influence on European binding: a report on the exhibition of "History and Bookbinding," at the Baltimore Museum of Art, 1957-58. *Ars Orientalis*, vol. 3, pp. 113-131, pls., 1959.
- . New light on early animal carpets. In *Aus der Welt der islamischen Kunst: Festschrift für Ernst Kühnel*. Berlin, pp. 93-116, 1959.
- . On some Mongol miniatures. *Kunst des Orients*, vol. 3, pp. 44-65, illus., 1959.
- . Tadhhib (Illumination). *Urdu encyclopedia of Islam*, Lahore, vol. 1, 12 pp., 28 figs., 1959.
- . Tajlid (Bookbinding). *Urdu encyclopedia of Islam*, Lahore, vol. 1, 13 pp., 18 pls., 1959.
- . Un tissu de la première époque Ottomane. *Papiers premier congrès international des arts turcs . . .* (Université d'Ankara), pp. 87-88, 1959.
- . Review of "Iran; Persian miniatures—Imperial Library," compiled by UNESCO, Greenwich, Conn., New York Graphic Society, 1956. *Ars Orientalis*, vol. 3, pp. 217-220, 1959.
- . Review of "Islamic art and archaeology. A register of work published in the year 1954," by J. D. Pearson and D. S. Rice, Cambridge, Heffer & Sons, 1956. *Ars Orientalis*, vol. 3, pp. 215-216, 1959.
- . Review of "Islamic pottery from the ninth to the fourteenth centuries A.D. in the collection of Sir Eldred Hitchcock . . ." London, Faber & Faber, 1956. *Ars Orientalis*, vol. 3, pp. 216-217, 1959.
- GETTENS, RUTHERFORD J. The Freer Gallery Laboratory for technical studies in Oriental art and archaeology. *Studies in Conservation*, vol. 4, pp. 140-145, illus., 1959.
- . Review of "Studies in ancient technology," vol. 5, by R. J. Forbes, Leiden, E. J. Brill, 1957. *American Journal of Archaeology*, vol. 63, p. 285, 1959.
- POPE, JOHN A. Review of "Chinese celadon wares," by G. St. G. M. Gompertz, London, Faber & Faber, 1958. *Artibus Asiae*, vol. 21, pp. 290-295, 1958.
- . An early Ming porcelain in Muslim style. In *Aus der Welt der islamischen Kunst; Festschrift für Ernst Kühnel . . .* Berlin, Gebr. Mann, 1959, pp. 357-375, 9 figs., 14 pls.
- STERN, HAROLD P. [Arranging and cataloging the Hauge collection for] Japanese art in America: prehistory—A.D. 1900. Scripps College art galleries, April 19-May 15, 1960, Pomona, Calif., Day Printing Corporation, 30 pp., 34 pls., 1960.
- . Japan's earliest ceramics on tour. *Museum News*, vol. 38, no. 5, pp. 26-29, illus., Jan. 1960.
- . Masterpieces of Asian art in American collections . . . (Korean section) as shown in Asia House, January-February, 1960. New York, Carnegie Press, Inc., 64 pp., illus., 1960.
- . One hundred objects of Asian art from the Avery Brundage collection (at the) M. H. De Young Memorial Museum, San Francisco, May 10 to June 12, 1960. Korean and Japanese Sections. San Francisco, H. S. Crocker Co., 122 pp., cover illus., front, pls., 1960.



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Recent addition to the collections of the Freer Gallery of Art

- STERN, HAROLD P. Treasures of Japan; Seattle Art Museum, June 25 through August 21, 1960. Seattle, the Museum, 1960.
- . Review of "Hokusai; paintings, drawings and woodcuts," by J. Hillier, London & New York, Phaidon Press, 1957. *Journal of Asian Studies*, vol. 19, pp. 87-88, 1959.
- . Introduction to: Figure prints of old Japan, a pictorial pageant of actors & courtesans of the eighteenth century reproduced from the prints in the collection of Marjorie & Edwin Grabhorn . . . San Francisco, The Book Club of Canada, 1959.
- USILTON, BERTHA M. Compiled Index to Far Eastern Ceramic Bulletin, 1949-58, 8 pp., issued as separate for the bulletin, Oct. 1959.
- WENLEY, ARCHIBALD GIBSON. A parallel between Far Eastern and Persian painting. In *Aus der Welt der islamischen Kunst; Festschrift für Ernst Kühnel* . . . Berlin, Gebr. Mann, 1959, pp. 350-356, 4 pls.

PHOTOGRAPHIC LABORATORY AND SALES DESK

The photographic laboratory made 6,943 items during the year as follows: 4,816 prints, 567 negatives, 1,383 color slides, 160 black-and-white slides, and 17 color film sheets. In all, 3,225 slides were lent during the year.

BUILDING AND GROUNDS

The exterior walls appear to be sound and in good condition. The bronze doorways and area work surrounding the court were refinished under contract. The wooden flagpole was replaced with an aluminum one.

The structural steel in the attic was cleaned of rust and spotted with aluminum paint, pending the time when the attic can be completely repainted.

The cleaning of the limestone of the first floor was continued and is now about 75 percent complete.

The walls in galleries IX, X, and XI were removed and new plaster walls installed. The plaster was then covered with a vinyl resin coated fabric, resulting in a marked improvement.

The auditorium was redecorated and new floor covering installed.

All corridors and storage rooms in the basement were painted. The north wall of the south corridor leading to the auditorium was rebuilt. The shelving in the stone storage room was removed and new metal shelving ordered for this area. Two hand-rails were installed inside the north side of the building leading to both sides of the gallery corridors.

In the courtyard replacements were made in the two azalea beds on the south side, and 14 yards of zoysia grass were replanted on that side of the building. The plantings around the fountain made excellent showings. Vinca has been planted for the coming summer season and appears to be doing well.

ATTENDANCE

The Gallery was open to the public from 9 to 4:30 every day except Christmas Day. The total number of visitors to come in the main entrance was 120,077. The highest monthly attendance was in August, 16,183.

There were 2,682 visitors who came to the Gallery offices for various purposes—for general information, to submit objects for examination, to consult staff members, to take photographs or sketch in the galleries, to use the library, to examine objects in storage, etc.

AUDITORIUM

The series of illustrated lectures was continued as follows:

1959

- October 20. Robert T. Paine, Museum of Fine Arts, Boston, "Japanese Prints of Beauties of the Three Cities." Attendance, 188.
- November 10. Prof. Harald Ingholt, Yale University, "Buddhist Art of Gandhara, Native and Foreign Influences." Attendance, 152.

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- January 13. Prof. W. Norman Brown, University of Pennsylvania, "Vasanta Vilasa, an Illustrated Spring Poem in Old Gujarati." Attendance, 85.
- February 9. Dr. Sherman E. Lee, Cleveland Museum of Art, "Liang Ch'ing-piao: Silent Collector, Eloquent Collection." Attendance, 159.
- March 8. Prof. S. Howard Hansford, University of London, "Some Problems of Chinese Jades and Bronzes." Attendance, 132.
- April 12. Prof. George H. Forsyth, Jr., University of Michigan, "Byzantine Art at the Monastery of St. Catherine on Mt. Sinai." Attendance, 234.

On May 3 ceremonies were held in the Freer Auditorium for the second presentation of the Charles Lang Freer Medal to the Near Eastern scholar, Prof. Ernst Kühnel of Berlin, Germany, "for distinguished contribution to the knowledge and understanding of Oriental civilizations as reflected in their arts." On the platform were Minister Franz Krapf, representing the Ambassador of Germany, His Excellency the Ambassador of Iran, Ardeshir Zahedi, in honor of the IVth International Congress of Iranian Art and Archaeology meeting in Washington, Dr. Richard Ettinghausen representing the Freer Gallery of Art, and Dr. Leonard Carmichael, Secretary of the Smithsonian Institution, who made the presentation. Professor Kühnel responded with an address on the growth of interest in collections of Near Eastern art. This was followed by a reception in Gallery XVII. Attendance, 325.

Eight outside organizations used the auditorium as follows:

1959

- September 17. Daughters of the American Revolution special regents' meeting. Attendance, 272.
- October 29. Department of Health, Education, and Welfare, Food and Drug Division meeting. Attendance, 76.
- November 17, 18. Department of Agriculture, Federal Extension Service, meetings. Attendance, 117 and 75.
- December 15. Department of Health, Education, and Welfare, Food and Drug Division meeting. Attendance 25.

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- January 18. Department of Agriculture, REA conference. Attendance, 118.
- January 21. Department of Health, Education, and Welfare, Microbiology seminar. Attendance, 56.
- January 25, 26. Department of Health, Education, and Welfare, Food and Drug Division meetings. Attendance, 290 and 169.
- February 18. Department of Health, Education, and Welfare, Food and Drug Division meeting. Attendance, 72.
- March 17. Department of Health, Education, and Welfare, Food and Drug Division meeting. Attendance, 72.
- April 21. Department of Agriculture. Food and Drug Division meeting. Attendance, 68.
- May 2. The IVth International Congress of Iranian Art and Archaeology, all-day meeting. Attendance, 125.
- May 19. Department of Agriculture. Food and Drug Division of Pharmaceutical Chemistry, meeting. Attendance, 138.
- May 23. Indian Embassy, Educational Department, presented Mrs. Sarada Arundel in Indian dances with a talk given by Mrs. Rukmini Devi. Attendance, 284.

STAFF ACTIVITIES

The work of the staff members was devoted to the study of new accessions, objects contemplated for purchase, and objects submitted for examination, as well as to individual research projects in the fields represented by the collections of Chinese, Japanese, Persian, Arabic, and Indian materials. Reports, oral and written, and exclusive of those made by the technical laboratory (listed below), were made on 10,379 objects as follows: For private individuals, 7,004; for dealers, 1,484; for other museums, 1,891. In all, 1,021 photographs were examined, and 321 Oriental language inscriptions were translated for outside individuals and institutions. By request, 24 groups totaling 258 persons met in the exhibition galleries for docent service by staff members.

Three groups totaling 34 persons were given docent service by staff members in the storage rooms.

Among the visitors were 95 distinguished foreign scholars or persons holding official positions in their own countries who came here under

the auspices of the State Department to study museum administration and practices in this country.

During the year the technical laboratory carried on the following activities:

Objects examined by various methods, including microscopic and microchemical examination, X-ray diffraction and spectrochemical analysis, examination in ultraviolet light, and specific gravity determination:

Freer objects examined.....	86
Outside objects examined.....	135

The following projects were undertaken by the laboratory during the year:

1. For a period of four weeks in September, Miss Elisabeth West worked as a guest in the Chemistry Department, Brookhaven National Laboratory, Upton, Long Island, N.Y. Her project of spectrochemical analysis of some 30 inscribed ceremonial bronzes from the Freer collection, begun in 1958, was brought to completion.

2. Continued editorship of *IIC Abstracts* (*Abstracts of the Technical Literature on Archaeology and the Fine Arts*) published by the International Institute for Conservation of Museum Objects, London.

3. Continued systematic collection of data on the technology of ancient copper and bronze in the Far East.

4. Continued studies on the corrosion products of ancient metal objects.

By invitation the following lectures were given outside the Gallery by staff members (illustrated unless otherwise noted):

1959

July 14.	Mr. Gettens, at the International Institute for Conservation of Historic and Artistic Works, United Kingdom Group at the Institute for Archaeology, London, England, "Preliminary Technical Studies on Ancient Bronze Ceremonial Vessels." Attendance, 30.
October 20.	Dr. Ettinghausen, at Congress of Turkish Art in Ankara, Turkey. "The Anatolian Mosque" and "The Problems of Working with Subjects on Turkish Art."
October 23.	Dr. Ettinghausen, at Ankara, Turkey (Ankara University), to the First International Congress on Turkish Art, "An Early Ottoman Textile" and "Turkish Elements in the Decorative Arts." Attendance, 180 and 200, respectively.
October 25.	Dr. Ettinghausen, at banquet given by Governor and Mayor of Konya, to the First International Congress of Turkish Art, "The Miracle of Konya." Attendance, 180.
November 4.	Dr. Pope, at Harvard University, Cambridge, Mass., "Chinese Export Porcelains." Attendance, 150.
November 6.	Dr. Pope, at Harvard University, Cambridge, Mass., "Angkor." Attendance, 250.
November 6.	Dr. Ettinghausen, at University of Istanbul, Turkey, "Some Problems of Early Turkish Art." Attendance, 45.
November 9.	Dr. Pope, J. B. Speed Art Museum, Louisville, Ky., "Chinese Export Porcelains." Attendance, 85.
December 11.	Dr. Cahill, at Cleveland Museum of Art, Cleveland, Ohio, "Great Chinese Paintings in Far Eastern Collections." Attendance, 55.

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- January 11. Dr. Stern, in Richmond, Va., to the Council, Virginia Museum of Fine Arts, "Survey of Japanese Art." Attendance, 250.
- January 13. Dr. Pope, at Cosmos Club, Washington, D.C., to Cultural Affairs Officers, "Charles Lang Freer and the Freer Gallery of Art." Attendance, 70.
- January 14. Dr. Cahill, at Smithsonian Institution Regents' Annual Dinner, Washington, D.C., "Ku-kung (Palace) Museum in Formosa." Attendance, 26.
- March 10. Dr. Cahill, at Princeton University, Princeton, N.J., "On the Dating and Attribution of Some Early Chinese Landscapes." Attendance, 150.
- March 30. Dr. Cahill, at American University, "The Haiku in Japanese Poetry." Attendance, 20.
- May 9. Dr. Ettinghausen, at Walters Art Gallery, Baltimore, Md., "Special Exhibition of Persian Objects Arranged for the Fourth International Congress of Persian Art." Attendance, 107.
- May 19. Dr. Ettinghausen, at University of Pennsylvania, Philadelphia, "Interrelationship of Near Eastern and Indian Paintings during the Middle Ages." Attendance, 33.
- May 24. Mr. Gettens, in Boston, Isabella Stewart Gardner Museum, "Notes on Museum Laboratories Visited in England and on the Continent, Summer 1959." Attendance, 50.
- May 25. Mr. Gettens, in Boston, at the International Council of Museums luncheon, "Status and Program of the Rome Center." Attendance, 150.
- May 25. Mr. Gettens, in Boston, to the American Working Party of the *IIC Abstracts*, "Report on *IIC Abstracts*." Attendance, 15.
- June 15. Mr. Gettens, in Chicago, to the Microscopy Symposium for 1960 (held by McCrone Associates), "Microscope Examination of Art Objects." Attendance, 150.

Members of the staff traveled outside Washington on official business as follows:

1959

- June 14-
August 12. Mr. Gettens began a 2-month trip to Europe in June, visiting museums in Glasgow and Edinburgh. He attended, in Copenhagen, the Joint Session of the ICOM Commission for the care of paintings. This meeting was attended by about 60 delegates from museum laboratories from all over the world. A highlight of the session was a visit to the Carbon-14 Laboratory at Copenhagen University. He attended meetings of the International Council of Museums in Stockholm and visited several of the museums there, paying special attention to the world-famed collections of Oriental art and the newly established laboratory in the Museum and Office of Royal Antiquities. He viewed Far Eastern antiquities in the private collection of His Majesty King Gustav VI, at the Royal Palace. He went with the Conference to Drottningholm Palace where all members had been invited to meet the King, see the fine collec-

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tion of bronzes, tapestries, Royal portraits and objects of art, and to attend at the Drottningholm Palace Theatre, a special performance of the eighteenth-century comic opera "Il Maestro." Visits were made by the group to Skokloster Castle and to Uppsala. In London Mr. Gettens spent several days visiting laboratories and collections in the Courtauld Institute of Art, the National Gallery, the British Museum, the Victoria and Albert Museum, and the Tate Gallery. Of special interest was a visit to Appleby in Westmorland to discuss business matters with the printer of *IIC Abstracts*. Other visits included: Brussels, the world-famed Institut du Patrimoine Artistique de Belgique; in Zurich, the newly established Laboratory of the Swiss National Museum; in Naples, the Museo e Gallerie Nazionali di Capodimonte and the ruins of Pompeii. Return was via London where more museum visits and professional contacts were made.

- July 23-25. Dr. Stern, in Chicago, examined the following objects for possible inclusion in the Asia Society Museum Inaugural Show: 56 Japanese and Korean objects at the Chicago Art Institute; 30 Chinese and Japanese objects belonging to a private collection; 100 Chinese and Korean objects in the Junkung Collection; 24 Chinese jades and paintings that belong to the Chicago Museum of Natural History; and 16 Japanese and Chinese objects belonging to dealers.
- September 21-December 11. Dr. Ettinghausen, in Europe and the Near East, attended the First International Congress on Turkish Art in Ankara, Turkey, visited Israel, England, France, Germany, Austria, Italy, Greece, Ireland, Switzerland, Holland, and Belgium. While in Berlin, he attended the *Festschrift* presentation in honor of Prof. Ernst Kühnel.
- October 13-14. Dr. Stern, in Toronto, Canada, examined objects at the Royal Ontario Museum, Hart House, Lee Collection, University of Toronto, and the Canadian Customs Service.
- October 16-17. Dr. Stern, in New York City, examined objects at Metropolitan Museum, New York Public Library, and saw the Bonnier Exhibition.
- November 13-17. Mr. Gettens examined 15 Egyptian objects (bronzes) in Walters Art Gallery, Baltimore, Maryland; in New York attended a meeting of Advisory Council for a Center for Teaching and Research in Conservation (Institute of Fine Arts, New York University).
- December 2. Mr. Gettens, in New York City, examined bronze objects at Metropolitan Museum of Art.
- December 15-21. Dr. Stern, in New York City, examined objects in museums, galleries, and private collections.

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- January 5-7. Dr. Stern examined objects at dealers in New York City.
- January 6-7. Dr. Stern, in New York City, attended an exhibition of Japanese art at Asia House, sponsored by Japan Society.
- January 11. Dr. Ettinghausen, in Baltimore, visited the Persian Art Exhibition at Walters Art Gallery.

1960

- January 15-28. Dr. Cahill, in Geneva, Switzerland, worked on book with Albert Skira and members of his staff. He visited: Far Eastern Exhibitions in the Rijksmuseum in Amsterdam and in The Hague; in London, Far Eastern exhibits in the British Museum, at the Percival David Foundation; and in New York examined Chinese paintings in the hands of several dealers.
- February 21-March 23. Dr. Stern, in Seattle, San Francisco, Santa Barbara, Los Angeles, and Chicago, examined objects at dealers and in private collections.
- March 5-8. Mr. Gettens, in New York City, attended meetings of Standing Committee for Artists' Oil Paints and examined objects at dealers.
- March 11. Dr. Cahill attended Seminar at Princeton University on Yuan paintings. Attendance 7.
- March 28. Dr. Pope went to Taiwan where he served as chairman of the American Selection Committee for the Exhibition of Chinese Art Treasures, to be held in five American museums in 1961-62.
- April 22-30. Dr. Ettinghausen, in New York, Philadelphia, and Baltimore, attended the IVth International Congress of Iranian Art and Archaeology as a member and delegate. Presided at the session held at the Donnell Library Center in New York City; also gave the eulogy on L. A. Mayer. Examined objects at dealers, in museums and private collections.
- May 9. Miss West and Mr. Gettens, in Boston, attended the meetings of the International Institute for Conservation of Historic and Artistic Works held in the Isabella Stewart Gardner Museum and the Fogg Art Museum.
- May 10-19. Dr. Pope, in Manila, studied the collection of Chinese and Siamese ceramics excavated in the Philippines by Prof. H. Ottey Beyer. He also visited the excavation sites at Calatagan.
- May 25. Miss West and Mr. Gettens, in Boston, attended meetings of the American Working Party of *IIC Abstracts* held in the Statler Hotel. Miss West served as co-chairman of the Program Committee for the meeting; visited the plant of Baird-Atomic, Inc. and the Laboratory of the Museum of Fine Arts. Mr. Gettens examined objects at the Museum of Fine Arts.
- May 25-27. Miss West and Mr. Gettens, in Boston, attended the meetings of the American Association of Museums.
- June 13-17. Mr. Gettens, in Chicago, attended the Microscopy Symposium, 1960, held by McCrone Associates; also examined objects in a private collection.
- June 3. Dr. Ettinghausen, at the Textile Museum, examined (as member of the Acquisition Committee) 40 Peruvian objects, 5 Mexican objects, 1 Turkoman, and 30 Indian printed cottons.

As in former years, members of the staff undertook a variety of peripheral duties outside the Gallery, served on committees, held honorary posts, and received recognition.

The Freer Gallery of Art again participated in the Wellesley-Vassar Washington Summer Intern Program designed for students interested in obtaining a rounded experience in the general operation and purposes of a gallery, and in broadening familiarity with the field of art in general. Through our error, the 1958-59 report should have named Miss Margo Parsons and Miss Elizabeth Chanler as interns for 1958. Miss Nancy Orbison, Vassar College, Poughkeepsie, served as our volunteer for the program during this summer.

Respectfully submitted.

A. G. WENLEY, *Director.*

Dr. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

Report on the National Air Museum

SIR: I have the honor to submit the following report on the activities of the National Air Museum for the fiscal year ended June 30, 1960:

Substantial progress was made on preliminary studies for the new National Air Museum building. The architectural firm of Harbeson, Hough, Livingston & Larson assisted in this work and presented several possible building concepts. One of these has been selected for further consideration when planning funds for the building are made available.

Among the many significant accessions received during the year were: A full-scale replica of the Atlas rocket and nose cone; three original Farre paintings; the C. G. B. Stuart collection of aviation photographs and books; the Lindbergh Lockheed "Sirius" airplane; a bronze portrait of Gen. James H. Doolittle; the Ryan X-13 "Verti-jet"; original letter carried as the first space mail; and the "Able-Baker" space capsules.

The Aircraft Building was completely renovated and a new exhibit was installed, which was not only an improvement over the former one but provided much valuable experience in planning the exhibit for the proposed new Air Museum building. The building was opened to the public on April 15. By June 30, 292,406 visitors to this exhibit had been counted.

A number of boxed aircraft were moved from indoor to outdoor storage, with suitable protection, to provide indoor storage space for about 30 historic airplanes which have been held for some years for the Air Museum by the United States Navy.

Information service again increased in scope and volume during the year. This included the furnishing of technical, historical, and biographical information pertaining to the development of air and space flight to Government agencies, schools, research workers, authors, students, and the public. Many useful acquisitions to the Museum's library, reference, and photographic files were received, including collections of 30,000 aviation photographs and 1,400 volumes of early aviation history.

The curatorial staff during the year completed the research for and the writing of approximately 800 labels for the new Aircraft Building exhibit.

ADVISORY BOARD

A meeting of the Advisory Board was held on December 16, 1959. The Secretary of the Smithsonian Institution welcomed the new members of the Board, Maj. Gen. Brooke C. Allen, U.S.A.F., and Rear Adm. P. D. Stroop, U.S.N. The Board expressed approval of changing the name of the National Air Museum to the National Air and Space Museum, at an appropriate time, to reflect the widening responsibility of the Museum in the field of historic space flight. The Board also discussed generally the requirements for the new Air Museum building.

SPECIAL EVENTS

A number of presentation ceremonies of note were held during the year. Among these were the presentation of a sculpture of James H. Doolittle by H. S. M. Burns, president of the Shell Oil Co.; the C. G. B. Stuart collection of aviation books by Richard Fell, president of the National Aviation Club; and an Atlas rocket and nose cone by the Secretary of the Air Force, Dudley C. Sharp. The Atlas ceremony was combined with the Langley Medal award, posthumously, to Dr. Robert H. Goddard. Senator Clinton P. Anderson, regent, presented the medal to Mrs. Goddard, and Congressman Overton Brooks, Smithsonian regent, accepted the Atlas for the museum.

A six weeks' course in air and space science, for graduate credit, was held at the Air Museum in cooperation with American University. Funds from the Link Foundation provided scholarships for the seven mathematics and science teachers who completed the course.

The Director attended the annual conference of the National Aviation Education Council at Denver, Colo., and addressed a panel on the "International and Economic Aspects of the Space Age." He also addressed the annual alumni meeting of the Academy of Aeronautics in New York.

Paul E. Garber, head curator and historian of the Air Museum, was honored at the Denver Conference of the National Aviation Education Council as the recipient of the National Frank G. Brewer Trophy. This award for outstanding service in aviation education was made by Jacqueline Cochran, president of the National Aeronautic Association.

Mr. Garber represented the Museum at a number of aviation meetings during the year, including the Air Force Historical Association and the Honors Night banquet of the American Helicopter Society. He delivered 30 lectures during the year, including one at the U.S. Air Force Academy.

IMPROVEMENTS IN EXHIBITS

The historic "Vin Fiz," "Winnie Mae," and "XR-4" airplanes were completely restored and preserved, the "Phantom" and "Bell X-1" were renovated, and all have been placed on exhibition in the Aircraft Building. Also, a dozen famous engines and many other historic objects were restored, preserved, and placed on display. New methods of display and protection are being tested in this new exhibit.

REPAIR, PRESERVATION, AND RESTORATION

The facilities for accomplishing proper restoration and preservation of the Museum's aeronautical collections were improved considerably during the year. Utilizing one of the storage buildings at Silver Hill, Md., the Museum can now undertake the extensive program of restoration and preservation in preparation for the new building.

ASSISTANCE TO GOVERNMENT DEPARTMENTS

The Air Museum continued its service to various Government departments during the year. Among these were the Department of Justice (in patent litigation), the Voice of America, the Department of the Air Force, and the Department of the Navy.

PUBLIC INFORMATION SERVICES

Through its information service, the Museum has handled thousands of requests during the year for technical, historical, and biographical information from publishers, authors, schools, colleges, research workers, students, and teachers. The historical research required for this service requires a substantial part of the time of the curatorial staff and assistants.

REFERENCE MATERIAL AND ACKNOWLEDGMENTS

Many useful and valuable additions to the reference files, photographic files, and library of the Museum were received during the year. These records and documents are helpful to the Museum staff in providing information, authenticating data, and for historical research.

The cooperation of the following persons and organizations in providing this material is sincerely appreciated:

AERO DESIGN & ENGINEERING Co., Bethany, Okla.: A series of 8-x-10" photographs and brochures pertaining to the Aero Commander.

AIR FORCE, DEPARTMENT OF THE, AIR FORCE MUSEUM, Wright-Patterson Air Force Base, Ohio: Transfer of 15 reels of varying lengths of film on early flight; Technical Reports (Army), four boxes of duplicate reports.

AIR PHOTOGRAPHIC AND CHARTING SERVICE, USAF, Pentagon, Washington, D.C.: 40 photographs of different aviation subjects.

- AIR PHOTOGRAPHIC SQUADRON, 1350th, Wright-Patterson Air Force Base, Ohio: 16-mm. film copy of Fokker T-2 coast-to-coast flight, 1923.
- ANDREWS, JOHN H., Paradise, Pa.: "The Wise Story." Items: 3 newspapers, souvenir booklet, and first-day cover commemorating 100th anniversary of John Wise's first airmail flight from Lafayette, Ind.
- ARMY BALLISTIC MISSILE AGENCY, Huntsville, Ala.: Motion-picture film "Nose Cone Voyagers."
- ARMY ORDNANCE COMMAND, Pentagon, Washington, D.C.: Motion-picture films "Launch of the Jupiter C Explorer" and "Guided Missiles."
- AUTONETICS MOTION PICTURES, through A. V. MATTUCCI: Motion-picture film "Inertical Navigation."
- AVIATION HISTORY PUBLICATIONS, Concord, Calif.: Book "U.S. Marine Corps Aircraft 1914-1959," William T. Larkins.
- BEECH AIRCRAFT CORP., Wichita, Kans.: News release and 6 photographs with description of the aircrafts—1960 models.
- BELL, DAVID R., Caldwell, N.J.: Postal card sent from Europe by Orville Wright to Miss Hoffman.
- BELL AIRCRAFT, COL. S. G. McLENNAN, Washington, D.C.: 2 photographs of "X-9 Strike" missile being launched from B-29.
- BRAINARD, HENRY A., Akron, Ohio: Documents relating to Professor Langley.
- BREESE, SYDNEY S., Sarasota, Fla.: Letter received Sept. 17, from Sydney S. Breese giving history of Breese Penguin plus an 8-x-10" drawing by a French Ace of the type of taxi trainer used in France during WWI, plus a 2-x-4" photograph of a biplane built by Breese in 1916 in which the first Lawrence air-cooled aluminum engine was tested.
- BROWN, JAMOR KENILEWIGLE S., VSAF, Bedford, Mass.: Tapestry of Lindbergh and "Spirit of St. Louis."
- CANADAIR LTD., Montreal, Canada: 3-view drawings of Canadair-Convair 540, Canadair CL-28, and Canadair CL-44.
- CESSNA AIRCRAFT Co., Wichita, Kans.: 3 8-x-10" prints of Cessna 310 being used for business flying.
- CLARK, MISS ROSAMOND, Baltimore, Md.: Booklet, Harvard-Boston Aero Meet, Aug. 26-Sept. 4, 1911, official program.
- COOKE, DAVID C., Valley Stream, L.I., N.Y.: Book, "Transport Planes that made History," by David Cooke.
- DELEOR, FRANK J., SIKORSKY AIRCRAFT, Stratford, Conn.: 3 photographs of Sikorsky helicopters used in Korea and 1 photograph each of 1909 and 1910 helicopters.
- DOAK AIRCRAFT Co., Torrance, Calif.: Photographs of Doak VZ-4DA VTOL aircraft.
- DOUGLAS AIRCRAFT, Washington, D.C.: 7 photographs of a Douglas DC-3.
- DOUGLAS, GEORGE F., ENGINEERING NORAIR, Hawthorne, Calif.: 3 1:72-scale engineering drawing of Northrop XP56 and 1 1 20:20 "blow up."
- DOVE, ROGER, SIKORSKY AIRCRAFT DIVISION, Stratford, Conn.: 14 8-x-10" photographs, 1 advertisement proof, 2 10-x-12" photos.
- EMME, EUGENE, Historian, NASA: Book, "The Impact of Air Power," Emme.
- FALLA, NELSON, CONVAIR GENERAL OFFICES, San Diego, Calif.: Photographs of the B-24, Ref. Material on B-24, 800 and 600.
- FIAT AVIATION DIVISION, Tarino, Italy: 90 photographs of Fiat aircraft.
- FOGEL, JOHN MARTIN, Baltimore, Md.: Motion-picture film made by Martin Aircraft Co. of 7 models borrowed from the National Air Museum.

- FRANKLIN INSTITUTE, Philadelphia, Pa.: Photographs of Amelia Earhart's Lockheed Vega (one is model of plane); 12 sound films "Simulo Streams" (part of a series of 13 half-hour programs for Educational TV given by Dr. Lippisch of Collins Radio).
- GIBSON, R. J., QANTAS EMPIRE AIRWAYS, LTD., Sydney, Anstralia, also F. R. MORRISON: "The Aeronautical Work of Lawrence Hargrave," by T. C. Ronghley, B.Sc., Bulletin 19, Technological Museum, Sydney, Australia.
- GRANT, DR. ROBERT, JR., San Diego, Calif.: Negatives of photographs taken by N. E. Brown of Lincoln Beachey around 1908-10 at Long Beach, Calif.
- GRIFFON, MILT S., THOMPSON PRODUCTS DIVISION., Cleveland, Ohio: The Thompson Products Hubbell lithographs for 1941 captioned "Dawn of Wings." One set of twelve.
- GRUMMAN AIRCRAFT CORP., Bethpage, L.I., N.Y.: Drawings, photographs, and specifications of Grumman Aircraft from the 1930's to the present time.
- HAJIME TAKOGI, Editor, Tokyo, Japan: 14 photographs of Japanese aircraft.
- HALL, GEORGE H., NORTH AMERICAN AVIATION, International Airport, Los Angeles, Calif.: 1 booklet on the "X-15" and 20 pictures of the "X-15" and her mission.
- HALL, COMDR. G. M., USN, OFFICE OF INFORMATION, Washington, D.C.: 2 8-x-10" glossy prints of each of the following: U.S.S. *Ticonderoga* (CV-14) and other ships of the fighting fleet in Utihi Atoll (12-8-44). Platform of U.S.S. *Pennsylvania* (BB-38) completed for Ely's experiment January 1911; Ely taking off *Pennsylvania* (1-18-11), Ely landing on *Pennsylvania*, front and side view (1-18-11). USN Neg. 294131, 65693, 418709.
- HENRY, LOIS, HENRY PUBLICATIONS, New York, N.Y.: 2 photographs: Winners of the 1959 Powder Puff Derby, Sikorsky A/C Ser. No. X802W, operated by Kane Laboratories, Inc.
- HERFORD, PEGG, Los Angeles Dept. of Airports, Los Angeles, Calif.: Photographs of Los Angeles International Airport—(1) 1929, (2) 1959, showing development.
- HOWARD, JEAN ROSS, ASSISTANT TO DIRECTOR, HELICOPTER COUNCIL: Reference material on heliports.
- IMMENSCLUCK, W. T., RYAN AERONAUTICAL CO., San Diego, Calif.: Log books (copies) of the Curtiss Navy A-1 and B-1 (AH-4) aircraft.
- JUERGENS, PHILIP L., Burbank, Calif.: 1 3-view drawing 16-x-23" of Lockheed pings and other memorabilia pertaining to and associated with the life of XC-35, 5 photographs on 3-view drawing of XC-35, 5 photographs on 3-view drawing of the Lockheed Vega; 7 photographs of "X-7" Lockheed missile.
- JUPTNER, JOSEPH P., Orange, Calif.: 12 photographs of aircraft.
- KEY, WILLIAM G., WILLIAM G. KEY ASSOCIATES, Washington, D.C.: "Controversy in the Making," by William G. Key (Pegasus Supplement).
- KNABENSHUE, MRS. ROY A.: Collection of books, blueprints, photographs, clippings and other memorabilia pertaining to and associated with the life of Roy A. Knabenshue.
- LIBRARY OF CONGRESS, EXCHANGE AND GIFT DIVISION: Photographs from Grover C. Loening papers.
- LICHTEN, R. L., BELL HELICOPTER CORP., Fort Worth, Tex.: Bell XV-3 Convertplane folder, 8-x-10" photograph in color.
- LINK, EDWIN A., Binghamton, N.Y.: Miscellaneous photographic prints.
- LOCKWELL, WARREN T., HILLER HELICOPTER, Washington, D.C.: Photograph and reference material on the X-18 tilt-wing research aircraft.
- LONGO, ROBERT R., Tyler, Tex.: "Stepchild Pilot," by Joseph Doerflinger.

- LUFTHANSA, DEUTSCHE, Köln, Germany: Photographs of Fokker F-2 and F-3 aircraft as used by Lufthansa.
- MARQUETTE COUNTY HISTORICAL SOCIETY, Marquette, Mich.: Collection of early airline labels, baggage stickers and tags. (From Dr. John N. Lowe collection.)
- MARTIN COMPANY, Baltimore, Md.: Motion-picture film, "Project Vanguard," color-sound 28 minutes.
- MASSIN, ALEX, Toronto, Ontario, Canada: 12 commemorative covers (envelopes), 5 aviation magazines (1928-1929.)
- MATTES, M. A., STANDARD OIL CO. OF CALIFORNIA, San Francisco, Calif.: 8 8½-x-14" originals from which the following Standard Oil Co. of California "Plane Fax" advertisements show uses of aircraft were derived; "Specialists in Rugged Flying," "Flying the Yukon Air Trials for 'Black Gold,'" "Delivering Groceries to the Sierra Crest," "1,134 Hours between Majors—No Repairs," "Planting Trout by Air into Cascade Lakes," "Breaking Trail By Air for Alaska Train," "Flying Life-or-Death Missions in the High Sierra," and "300-mile Flight Wins \$1,000,000 Job."
- MCDONNELL AIRCRAFT CORP., St. Louis, Mo.: 5 photographs of the XV-1 helicopter; motion-picture film, "The Phantom," color-sound 15 minutes.
- MCLENNAN, COL. S. G., Washington, D.C.: 2 photographs of "X-9 Strike" missile being launched from B-29.
- MELOTTI, G., OF FIAT, AVIATION DIVISION, Torino, Italy: 11 blueprints (2 sets) and 13 photographs (7" x 9½") pertaining to the AVS-5 airplane.
- MORGAN, LEN, Dallas, Texas: Books, "Sound Barrier," "Flying Lovers," "Everyman to His Post," "Trans Pacific Flight," "Wingover the World," "Fighter Pilot," "Air Officers Guide," Squadron Admin., "Air Warfare"; Popular Flying magazines.
- MORRIS, KEITH, SPORTS ILLUSTRATED: Famed color photograph of Istel making parachute jump.
- MUELLER, MISS ESTER, Air Force Museum: 332 photographs, 20 negatives.
- NAVY, DEPARTMENT OF THE, Washington, D.C., BUREAU OF AERONAUTICS: 3-view and other drawings of 8 naval airplanes: Consolidated NY-1, Boeing PB-2, Curtiss R3C-1, and R3C-2, Curtiss F6C-3, Martin MS-1, Huff Daland HN-2, Flias EM-2; 15 drawings of early naval aircraft, Loeing-3. BUREAU OF NAVAL WEAPONS: 2 copies each log books for Navy Curtiss Flying Boat No. C-1 and Wright Hydroaeroplane No. B-2.
- NORTH AMERICAN AVIATION, AUTONETICS DIVISION, Downey, Calif.: Motion-picture film, "Inertical Navigation."
- O'DEA, W. T., DEPARTMENT OF AERONAUTICS, SCIENCE MUSEUM, London, England: 17 6½-x-9½" drawings, 21 6½-x-9½" photographs, Vickers Vimy cockpit and controls, 2 2½-x-4½" drawings of Vickers Vimy cockpit.
- O'HEAR, W. M., UNITED AIRLINES, Chicago, Ill.: 4 photographs of United Airlines maintenance base at San Francisco, Calif.
- PARRISH, WAYNE W., Washington, D.C.: 3 bound volumes of American Aviation and 1 American Aviation Daily.
- POST OFFICE DEPARTMENT: Copies of texts pertaining to the first balloon airmail in the U.S.A. authorized by the Post Office Department and carried in the John Wise balloon "Jupiter" in 1859.
- RICE, C. E., Odell, Nebr.: 11 newspaper clippings and 1 reprint of Chicago Sunday Tribune of May 22, 1927.
- ROBINSON, BILL, CESSNA AIRCRAFT Co., Wichita, Kans.: 3 8-x-10" prints of Cessna 310 being used for business flying.
- SHEAFFER, MRS. DANIEL, Wayne, Pa.: Photographs, framed pictures, books, pamphlets, and other graphic or text items.

- SIKORSKY AIRCRAFT, Stratford, Conn.: 2 photographs of C. L. Morris, pilot of Sikorsky XR-4; photographs of Sikorsky's S-38, S-39, Martin Johnson's "Osa's Ark", and "Spirit of South Africa"; 2 photographs 8" x 10" of Sikorsky HSS-2 helicopter.
- STANDARD OIL Co., San Francisco, Calif.: 7 proofs of "Plane Fax" advertisements showing uses of aircraft.
- STEPHENSON, ROBERT L., Lincoln, Nebr.: Photographs and negatives of the Nathaniel Dewell collection.
- STRICKLER, MERVIN K., DIRECTOR OF AVIATION EDUCATION, Ellington Air Force Base, Texas: Complete set of textbooks used in C.A.P. cadet training program.
- STROCK, ROBERT D., WEN-MAC CORP., Los Angeles, Calif.: Control line model of P-38 having a 2-foot wingspan, and equipped with 2 gasoline engines.
- STROHMEIER, WILLIAM D., DAVIS, PARSONS & STROHMEIER, INC., New York, N.Y.: 4 brochures illustrated in color, describing the Piper line of aircraft, and 13 8-x-10" glossy photographs.
- STUART, C. G. B., Hastings, Sussex, England: Air Britain Digest, unbound copies dating back to earliest issues.
- SULLIVAN, WENDELL R., BEECH AIRCRAFT CORP., Wichita, Kans.: 11 photographs and 6 3-view drawings of 1960 aircraft.
- SYVERSON, J. M., NORTH AMERICAN AVIATION, INC., Downey, Calif.: 9 views (photographs) of the North American "X-10," and a news release.
- TODA, MANNOSAKE, Tokyo, Japan: 25 photographs of aircraft.
- TURBO CHAMBER OF COMMERCE, North Truro, Mass.: Scrapbook of tests of German gliders made at Corn Hill, Mass., 1928.
- UNITED AIRLINES, Chicago, Ill.: 4 8-x-10" photographs, 2 of the Link Electronic Jet Engine Simulator (first used by United Airlines), and 2 of the United Airlines DC-8 Jet Mainliner; 2 photographs of Laird Swallow aircraft.
- U.S. NAVAL PHOTOGRAPHIC CENTER, Naval Air Station, Anacostia, D.C.: 12 photographs of A/C carriers operations, 2 photographs of balloon carriers operations, 1 photograph of R4D operating office.
- U.S. NAVAL RESEARCH LABORATORY, Washington, D.C.: Photographs of Vanguard, chart of course and related photographs.
- VADNEY, H. A., DEPARTMENT OF THE NAVY, Washington, D.C.: Drawings of early naval aircraft.
- WATERS, LT. COL. JAMES I., USAF, Washington, D.C.: 14 8-x-10" glossy photographs of parachutes being used to lower cargo and to reduce landing roll of aircraft.
- WELLS, FRED T., PRATT & WHITNEY AIRCRAFT, East Hartford, Conn.: Pratt & Whitney JT3D Turbo Fan data, 8-x-10" photograph (cutaway view), Pratt & Whitney booklet, "It's a Smaller World," Aviation Week reprint of January 26, 1959.
- WETTING, DR. OLAR, Oslo, Norway: Photographs of Norge and Triggvi Gran and Roald Amundsen.

ACCESSIONS

Additions to the National Aeronautical Collections received and recorded during the fiscal year 1960 totaled 287 specimens in 90 separate accessions, as listed below. Those from the Government departments are entered as transfers; others were received as gifts.

AERO DESIGN & ENGINEERING Co., Bethany, Okla.: Scale model of "Aero Commander" L-26, with color scheme the same as that of President Eisenhower's personal plane. (N.A.M. 1104.)

- AIR FORCE, DEPARTMENT OF THE, Washington, D.C., through RYAN AERONAUTICAL Co.: Ryan X-13 "Vertijet" airplane, first jet-powered vertical takeoff aircraft to demonstrate transition from horizontal to vertical flight and return to horizontal flight configuration. (N.A.M. 1067.) DAYTON PROCUREMENT DISTRICT, Wright-Patterson Air Force Base, Ohio: 1 experimental twin-jet turboprop engine, YT-40-A-6, complete with gear boxes, contrarotating propellers, and additional duplicate assemblies. (N.A.M. 1135.) 4TH WEATHER GROUP, Suitland, Md.: Weather maps and charts used in briefing flight crew for Vice President Nixon's flight to Moscow, July 1959. (N.A.M. 1066.) AIR FORCE MUSEUM, Wright-Patterson Air Force Base, Ohio: 25 aircraft engines (N.A.M. 1088), complete rocket assembly for V-2 German guided missile, including combustion chamber and propulsion unit (N.A.M. 1062), 9 turbojet and one turboprop engines (N.A.M. 1133). AIR FORCE MUSEUM, Fairborn, Mich.: Lockheed "Sirius" monoplane, NR-211, formerly owned and used by Charles A. and Anne Morrow Lindbergh in their historic trip to the Orient and for their Atlantic survey flights. (N.A.M. 1063.) OFFICE OF THE SECRETARY, Washington, D.C.: A static test specimen of an Atlas ICBM, capable of intercontinental range and from which the first broadcast from space was made by President Eisenhower. It will be the vehicle used to launch the Mercury Man in a space capsule. (N.A.M. 1142.) WARNER ROBINS AIR FORCE BASE, Georgia: Complete E-6 radar fire-control system as used on F-86's and F-94's. (N.A.M. 1112.) PARK RIDGE DEPOT, Illinois: Collection of World War II specimens collected by order of General H. H. Arnold, USAF (recorded in National Air Museum Annual Report of 1949). (N.A.M. 1144.)
- ALEXANDER, ROLAND K., Watervliet, N.Y.: Loan of 3 famous World War I combat aircraft models—the DeHavilland DH-4, Ansaldo SVA, and the Sopwith Triplane. (N.A.M. 1131.)
- ALEXANDER, W. W., Grand Rapids, Mich.: Scale model of the Salmson 2-A2 reconnaissance bomber used by American Forces during World War I. The aircraft is of French design and construction. (N.A.M. 1119.)
- AMERICAN HELICOPTER SOCIETY, INC., New York, N.Y.: Feinberg Memorial Award which is presented annually to "the outstanding helicopter pilot of the year." (N.A.M. 1129.)
- ARMY, DEPARTMENT OF THE, BALLISTIC MISSILE AGENCY, Huntsville, Ala.: 2 complete life-sustaining space capsules and cradles used in the "Able-Baker" experiment. (N.A.M. 1122.) ORDNANCE, Washington, D.C.: Set of 11 1:24 scale models of U.S. Army rocket missiles. (N.A.M. 1134.)
- BEACHEY, HILLERY, San Carlos, Calif.: Silver loving cup trophy won by Lincoln Beachey at the International Aviation Meet held in Chicago, August 12-20, 1911. (N.A.M. 1136.)
- BELL AIRCRAFT CORPORATION, Buffalo, N.Y.: 1:16 scale model of the Bell X-14 jet-powered VTOL. (N.A.M. 1117.)
- BELL HELICOPTER CORPORATION, Fort Worth, Tex.: Model of the Bell XV-3 Convertiplane which embodies the best features of the helicopter and fixed-wing aircraft. (N.A.M. 1097.)
- BLACKALL, FREDERICK S., JR., Woonsocket, R.I.: Loughheed engine of very unique design combining features of both the 2- and 4-cycle operating principles in an 8-cycle air-cooled V-type engine, designed by Victor Loughheed. (N.A.M. 1110.)
- BOEING AIRPLANE Co., Seattle, Wash.: 1:72 scale model of the Boeing B-29 "Enola Gay" which dropped the first atomic bomb on August 6, 1945 (N.A.M. 1107.); model of the Boeing Model 707 aircraft scaled 1:48, representing the first jet transport of U.S. manufacture to enter airline service (N.A.M. 1060).

- BRANIFF INTERNATIONAL AIRWAYS, Dallas, Tex.: 14 equiscale models of aircraft used by Braniff Airways since the beginning of their operation (N.A.M. 1140); 1:48 scale model of the Douglas DC-7C airliner, designed for long-range and over-ocean flying (N.A.M. 1081).
- BRIGHT, MR. AND MRS. ROY D., Washington, D.C.: 1 complete dinner-service setting from the Graf Zeppelin, including 10 pieces of sterling silverware and 10 pieces of Bavarian china. (N.A.M. 1064.)
- BRONTE, E. B., Honolulu, Hawaii: Flyer's helmet worn by donor in flight from Oakland, Calif., to Molokai, Hawaii, July 14-15, 1927. (N.A.M. 1123.)
- CAPITAL AIRLINES, Washington, D.C.: 1:48 scale model of Capital Airlines' "Viscount," first operational turboprop airliner in the U.S. (N.A.M. 1095.)
- CARRUTHERS, MRS. JOHN, Pasadena, Calif.: Large leather- and cloth-bound scrapbook of early aviation items on ballooning, mostly 18th and early 19th century. (N.A.M. 1130.)
- CESSNA AIRCRAFT Co., Wichita, Kans.: Scale model of Cessna L-19 Army liaison plane. (N.A.M. 1076.)
- COCHRAN, JACQUELINE, New York, N.Y.: 2 trophies marking some of the high points in the distinguished career of this outstanding aviatrix—one from the Air Force Association (1948) for distinguished service; the other, the Vincent Bendix Trophy for the speed race from the West Coast to Cleveland (1938). (N.A.M. 1094.)
- CONVAIR, DIVISION OF GENERAL DYNAMICS CORPORATION, San Diego, Calif.: 1:48 scale model of the all-Jet Convair 880 airliner. (N.A.M. 1109.)
- CROMWELL, JAMES H. R., New York, N.Y.: Portraits in oil of World War I aviators, Maj. Lufbery, Capt. Duellin, and Lt. Flauhaire, painted by the eminent French artist, Henri Farre. (N.A.M. 1059.)
- DAVIS, MRS. ARLENE, Cleveland, Ohio: 2 aviation trophies from donor, 1 a loving cup given by the National Intercollegiate Flying Association and the other the Cessna Trophy for first arrival in the All-Women Transcontinental Air Race, 1951. (N.A.M. 1093.)
- DEMICK, H. E., Washington, D.C.: Italian altimeter with special barometric-pressure and temperature feed-in corrective attachments. (N.A.M. 1137.)
- DOOLITTLE, GEN. JAMES H., Los Angeles, Calif.: 59 medals, awards, certificates, membership cards, etc., from the personal collection of the donor. (N.A.M. 1082.)
- DOUGLAS AIRCRAFT Co., Inc., Washington, D.C.: Model of the Douglas DC-8 turbojet-powered transport. (N.A.M. 1099.)
- DOWNING, MRS. FREDERICK B., Kinderhook, N.Y.: Flight clothing, consisting of leather coat and 3 helmets worn by the late Rear Adm. J. Lansing Callan (died 1958), who learned to fly at the Glenn H. Curtiss School in 1911, commanded Naval flight operations in Europe during World War I, served with distinction in World War II, and retired in 1948. (N.A.M. 1056.)
- ECKER, HERMAN A., Fort Lauderdale, Fla.: A "Kingston" carburetor from a Roberts' aviation engine, used by the donor in 1911 on his flying boat. (N.A.M. 1073.)
- EICHNER, E. C., Clifton, N.J.: An X strut from girder of "Shenandoah" and a piece of fabric from gas cell. (N.A.M. 1065.)
- FLEMING, WILLIAM N., Passaic, N.J.: Model, 1:16 size, of the Aerial Experiment Association (Curtiss) "June Bug," winner of the Scientific American Trophy July 12, 1908. (N.A.M. 1108.)
- FRENCH EMBASSY, Washington, D.C.: 9 French Government medals, duplicates of those awarded to members of the Lafayette Escadrille. (N.A.M. 1111.)

- GARBER, PAUL E., Washington, D.C.: 1910 edition of Trowbridge's narrative poem "Darius Green and His Flying Machine" and 1874 edition of Jules Verne's prophetic science fiction "From the Earth to the Moon" (N.A.M. 1075); contemporary color print of Henson's "Ariel" shown taking off from tower on the plains of Hindustan (N.A.M. 1098); scale reproductions of 2 early aircraft devised by Sir George Cayley, his glider kite and his aerial top. (N.A.M. 1078.)
- GLENN L. MARTIN Co., Baltimore, Md.: 2 1:48 scale models of the B57E and the B26 "Flak-Bait" (N.A.M. 1105); models of significant early Martin airplanes—the MB-1 bomber used during the Virginia Capes bombing tests and the Mail Express, a development of the bomber intended for carrying U.S. mail during the early part of the Air Mail Service. (N.A.M. 1138.)
- GODDARD, MRS. ROBERT, Worcester, Mass.: Loose-leaf album of photographs of Dr. Robert Goddard and his experiments from 1915 to 1945. (N.A.M. 1072.)
- GOOD, DR. WALTER A. and WILLIAM, Bethesda, Md.: A gasoline-engined radio-controlled model airplane designed, built, and flown by the donors. It is one of the first successful examples of this type of sport aircraft, and was winner of the radio-controlled flight events in the U.S. National Model Airplane meets for 1938, 1939, 1940, and 1947. (N.A.M. 1141.)
- GOODYEAR AIRCRAFT CORPORATION, Washington, D.C.: Model of Goodyear Airship 2PG-2W, cut away to show large radar antenna enclosed in the bag. (N.A.M. 1070.)
- HARTWICK, HERBERT, Marietta, Ga.: Model of Curtiss JN-4D World War I training plane. (N.A.M. 1103.)
- HAWKER AIRCRAFT LIMITED, Surrey, England: Model 1:10 size of the Hawker Hurricane fighter famous for its performance in World War II, particularly in the "Battle of Britain." (N.A.M. 1106.)
- HEINRICH, ALBERT S., Fort Ashby, Va.: Trophy awarded to donor by Municipal Engineers of the City of New York for Aeroplane General Efficiency Test. (N.A.M. 1085.)
- HILLER AIRCRAFT CORPORATION, Palo Alto, Calif.: Scale model of the Hiller helicopter, Model 12E, with agricultural spray equipment manufactured by Agravenco. (N.A.M. 1125.)
- INSTITUTE OF AERONAUTICAL SCIENCES, New York, N.Y.: Group of specimens including 6 aircraft models—1 of the "Akron"; an aileron; an Earhart loving cup; and 1 propeller. (N.A.M. 1118.)
- ISTEL, J. A., Orange, Mass.: "Skydiver" sport parachute designed and used by donor in several parachute jumping competitions, both national and international. (N.A.M. 1068.)
- JOHNSON, HARRY, JULIUS, & LOUIS, Coral Gables, Fla.: Scale model of Johnson Monoplane (1911) which incorporated a number of unusual features; also a trophy cup awarded to the donors in 1912 by the Terre Haute Boosters. (N.A.M. 1057.)
- LAYAT, FELIX, Plainfield, N.J.: Message pouch dropped by Maj. H. A. Dargue at Tacopilla, Chile, during U.S. Army Pan American goodwill flight around South America. (N.A.M. 1058.)
- LOCKHEED AIRCRAFT CORPORATION, Burbank, Calif.: 5 models historically significant, designed and built by Lockheed. (N.A.M. 1121.)
- MEDARIS, MAJ. GEN. J. B., Huntsville, Ala.: Original letter and envelope carried in the recovered nose cone on its historic flight, August 8, 1957. (N.A.M. 1090.)
- NATIONAL AVIATION CLUB, Washington, D.C.: Approximately 1,400 volumes of historically significant aviation books covering the field from the year 1700 to the present. (N.A.M. 1143.)

- NAVY, DEPARTMENT OF THE, Washington, D.C.: Curtiss P-40 fighter aircraft of World War II face (N.A.M. 1077). BUREAU OF SHIPS, Washington, D.C.: Dummy Regulus I missile (N.A.M. 1087); Upper Darby, Pa.: Allison YJ-71-A-4 turbojet engine, one of the first of this series tested operationally (N.A.M. 1124). BUREAU OF WEAPONS, Washington, D.C.: MacDonnell FH-1 "Phantom" carrier-based turbojet-powered single-seat carrier fighter (N.A.M. 1092); model of the USN airship "Akron" constructed 1:80 full size (N.A.M. 1139). NAVAL AIR MATERIEL CENTER, Philadelphia, Pa.: Antiexposure suit, ejection seat catapult, lap belt, 2 regulators, helmet, pressure suit, and 2 wing structures (N.A.M. 1116). TECHNICAL DATA DIVISION, Washington, D.C.: 2 arresting hooks from carrier-borne aircraft, one from an FSU Vought "Crusader" and the other from an F4D-I Douglas "Skyray" (N.A.M. 1080).
- NEVIN, ROBERT S., Denver, Colo.: Model of a Bleriot "Penguin" monoplane trainer used during World War I for the training of pilots, including the members of the famed Lafayette Escadrille. (N.A.M. 1096.)
- NEWCOMB, CHARLES J., Trappe, Md.: Models of historically famous air vehicles, including the Fokker DR-1, Fokker T-2 (F-IV), and the balloons by Montgolfier Brothers, Prof. Charles Wise, and John Wise. (N.A.M. 1126.)
- NEWKIRK, THOMAS A., Urbana, Ill.: Aircraft telegraph transmitting set and single-blade propeller. (N.A.M. 1069.)
- NEW MEXICO NATIONAL GUARD, Albuquerque, N. Mex.: Japanese World War II airplane, Nakajima Ki 43-2 (Oscar II) Army fighter, a development of the famed Zero fighter. (N.A.M. 1086.)
- NORD AVIATION, France: Scale model of the Nord "Griffon II" aircraft used by Maj. Andre Turcat who became first pilot in the world to exceed mach 2 in a ramjet-powered aircraft, thus winning the Harmon Trophy for 1959. (N.A.M. 1083.)
- PAGE, GEORGE A., JR., Reynoldsburg, Ohio: Model of Heinrich monoplane, winner of efficiency test, Municipal Engineers of New York, November 7, 1914; also half blade from propeller of Curtiss H-16 "Big Fish." (N.A.M. 1071.)
- PAN AMERICAN WORLD AIRWAYS SYSTEM, INC., New York, N.Y.: 2 models of historically significant aircraft—The Fokker F-7/3M and the Consolidated "Commodore" Flying Boat. (N.A.M. 1128.)
- PORTUGUESE GOVERNMENT: 1:16 scale model of "Santa Cruz" plane which made first flight across the South Atlantic in 1922, flown by Portuguese Navy pilots Cabral and Coutinho. (N.A.M. 1113.)
- PRINCE, FREDERICK, H., Old Westbury, N.Y.: American flag given to the Lafayette Escadrille by President Wilson. (N.A.M. 1115.)
- REPUBLIC AVIATION CORPORATION, Farmingdale, N.Y.: Model of the Republic F-105 "Thunderchief" fighter-bomber which has been described by the USAF as "The world's most powerful one-man airplane." (N.A.M. 1074.)
- RYAN, J. J., c/o Eric Wood, New York, N.Y.: Fulton Airphibian Model FA-3, the first certificated vehicle to incorporate the desirable features of both the airplane and the automobile. (N.A.M. 1089.)
- SCABITT, DANIEL, Gainesville, Fla.: 1 black leather folder containing Pilot's Identification Card #10 and Transport Pilot Rating #10 issued in 1927; Mechanic's Identification Card #10 and Mechanic's License #10 issued in 1927. (N.A.M. 1132.)
- SHELL OIL Co., New York, N.Y.: Less than life-size bronze bust of Gen. James H. Doolittle sculptured by Mme. Suzanne Silvercruys. (N.A.M. 1084.)
- SHOEMAKER, PETER, Baldwin, N.Y.: 1:16-size scale model of Heinrich Brothers' first airplane (1910), given by donor, builder of the model, and winner of a contest held among the students of Baldwin High School. (N.A.M. 1127.)

SIKORSKY AIRCRAFT, DIVISION OF UNITED AIRCRAFT CORPORATION, Stratford, Conn.: Model of the Sikorsky VS-300 helicopter, the first successful U.S.-built helicopter. (N.A.M. 1101.)

SIMMONS, MRS. OLIVER, Denver, Colo.: Original letter from Orville Wright. (N.A.M. 1120.)

SPACETRONICS, INC., Washington, D.C.: Early experimental model of ground cushion vehicle capable of carrying one person. (N.A.M. 1102.)

STUART, C. G. B., Sussex, England: A collection of approximately 30,000 aircraft photographs covering in scope all the countries of the world in which aircraft are manufactured. (N.A.M. 1061.)

TAYLOR, MR. AND MRS. REUBEN, SR., El Paso, Tex.: Small American flag carried on the Wright Brothers' airplane of 1904 at Huffman's Prairie, near Dayton. (N.A.M. 1079.)

TRACY, DANIEL, Lakewood, Ohio: 3 1:16 scale models—a Curtiss R3C-1, a Newport 11, and a Sopwith "Camel"—purchased from Daniel Tracy (N.A.M. 1100); 1:16 scale model of the Curtiss Navy Racer, the R2C-1, winner of the Pulitzer Trophy of 1923, also purchased (N.A.M. 1055).

VICKERS-ARMSTRONG, LIMITED, London, England: 1:16 scale model of the famous Supermarine "Spitfire," backbone of the Royal Air Force in the "Battle of Britain." (N.A.M. 1114.)

WEN-MAC CORPORATION, Los Angeles, Calif.: Commercial plastic 1:12 scale model of Hiller "Flying Platform" with special paint job done at Wen-Mac plant. (N.A.M. 1091.)

Respectfully submitted.

PHILIP S. HOPKINS, *Director.*

Dr. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

Report on the National Zoological Park

SIR: I have the honor to submit the following report on the activities of the National Zoological Park for the fiscal year ended June 30, 1960:

GIFTS

The past year was outstanding as far as gifts from foreign governments were concerned. In November the French community of African Republics presented President Eisenhower with "Dzimbo," a baby African elephant, which arrived in Washington after having been flown from the Brazzaville Zoo to the Vincennes Zoo in Paris and then across the Atlantic. The formal presentation was made on the White House lawn on October 12 by Dr. Jean Rinjard, associate director of the Vincennes Zoo.

President Habib Bourguiba of Tunisia presented two of the rare Dorcas gazelles to Mrs. John Eisenhower when she accompanied the President on his tour of Europe and North Africa in 1959. Having successfully passed through the required quarantine in Europe and again in New Jersey, these beautiful little antelopes arrived at the National Zoological Park on June 30, 1960.

The National Zoological Park has long been famous for breeding pygmy hippopotamuses. The sire, known as "Billy," died in October 1955, and efforts to replace him met with no success. It was therefore with particular appreciation that the Zoo accepted the offer of President William V. S. Tubman of Liberia to donate a male pygmy hippo of breeding age. Senior Keeper Charles W. Thomas was sent to Monrovia to accompany the animal on its journey to the States. The formal presentation of the hippo, named "Totota" after President Tubman's country estate, was made on February 5 by the Liberian Chargé d'Affaires Francis A. Dennis and accepted on behalf of the Smithsonian Institution by Dr. Remington Kellogg.

The arrival of an Indian rhinoceros in a zoo is always a very special event. Since the death of "Gunda" in January 1959, after nearly 20 years here, the National Zoological Park had been without an example of these great, armor-plated beasts. Early in 1959 the Forestry Service of Assam wrote to say that they had captured a rhinoceros for the National Zoo and were presenting it with the understanding that the Zoo would furnish transportation. The animal was young and barely weaned, and it was thought advisable to keep it in a

corral in Gahauti, where it lived for nearly a year. It was then brought by truck from Assam to the Alipore Zoo in Calcutta, and J. Lear Grimmer, Associate Director of the National Zoological Park, flew out to accompany it to Washington. He spent a month in India, supervising the crating of the rhinoceros and getting acquainted with it, even spending several nights in the Zoo, so that "Tarun" would become thoroughly accustomed to him. They arrived in Washington on May 25, and "Tarun" by that time tipped the scales at 2,000 pounds.

In addition to the rhinoceros, the Seaboard and Western plane that flew it to Washington carried the following animals which Mr. Grimmer had acquired as gifts, purchases, or exchanges:

1 spotted leopard	31 lesser ring-necked parakeets
1 black leopard	5 darters or snake birds
5 lesser pandas	2 black-backed kallege pheasants
1 langur	12 emerald-winged tree doves
12 blossom-head parakeets	5 yellow monitors
2 gray hornbills	1 water monitor
2 Bhutan or gray peacock pheasants	2 pythons
10 cotton teals	5 wolf snakes
3 greater ring-necked parakeets	

The National Zoological Park acknowledges not only the generosity of the Forestry Service of Assam but also the cooperation of R. K. Lahiri, director of the Alipore Zoo, and Gordon Mattison, American consul general in Calcutta, both of whom were most helpful in making arrangements.

Mrs. Grimmer, who accompanied her husband to India, was given a young leopard by Maj. Aubrey N. Weinman, director of the Zoo in Colombo, Ceylon, which she has recently presented to the National Zoo.

Dr. Robert E. Kuntz, stationed in Taiwan, continued to send rare and interesting specimens.

The *Washington Post* sent two newspaper carrier boys, winners of a "Junior Diplomat" contest, on a trip to Australia. While they were there, Sir Edward Hallstrom, president of the Taronga Park Trust, Sydney, gave them a pair of tree kangaroos for the National Zoological Park. The day after the kangaroos arrived in Washington, a very small young was noticed in the pouch. It is now half grown, and the trio make a most attractive exhibit.

The U.S. Coast and Geodetic Survey sent an expedition to little-known Swan Island, off the coast of Honduras, and collected for the National Zoological Park 7 Swan Island iguanas, 2 Nelson's Anolis, 3 *Sceloporus* spiny lizards, and a Nelson's gecko.

Ralph S. Scott, Washington big-game hunter, captured a baby tiger while on a trip to India last year. A contest was held to name it (win-

ning entry: Mighty Mo), and it was exhibited in various branches of a restaurant chain before being formally presented to the Zoo by J. Willard Marriott, Sr. Mr. Marriott also gave the Zoo its first audio device, a magnetic tape repeater sound system which at the press of a button recites the story of the young Bengal tiger.

James D. Kennedy, American administration personnel adviser to the Indonesian National Police, stationed in Djakarta, Java, sent a fine young cassowary. He later secured another one for the Zoo as a gift from his friend Police Colonel Mohamad Jasin, chief of the Indonesian Police Mobile Brigade, who wished to express his appreciation for the training he had received at Quantico, Va. Both birds are immature and are valuable additions to the collection.

Robert F. Kennedy gave a young female Californian sea-lion which had been sent to his children as a Christmas present and had been living in their swimming pool.

The list of benefactors of the National Zoological Park is a long one, and the following record of gifts received during 1959-60 mentions only those of unusual interest:

Berger, Paul, Berwyn Heights, Md., Javan macaque.

Blackwelder, Frank, Washington, D.C., scarlet king snake.

Brower, Charles F., Falls Church, Va., white-breasted toucan.

Call, Carl J., Silver Spring, Md., pectoral sandpiper.

Cobb, Dr. S., Boston, Mass., 4 albatrosses.

Crawford, Cecil C., Washington, D.C., Lady Amherst's pheasant.

Davis, M/Sgt. Dale E., Alhambra, Calif., tovi parakeet.

DePrato, Mario, Langley Park, Md., narrow-mouthed toad, 23 tree frogs (3 species of *Hyla*), king snake, scarlet snake, 2 cottonmouth moccasins, red-bellied water snake, 4 black racers, 7 brown water snakes, 2 southern banded water snakes, mud snake, 4 green snakes, chicken snake (*Elaphe*), 2 chicken snakes (*Deirochelys*), 21 spadefoot toads, 4 American toads, 3 bullfrogs, ring-necked snake, 2 mud turtles, box turtle, 62 newts.

Devaris, Capt. Dionisios P., Washington, D.C., Javan macaque.

Ereckson, Mrs. Lucy, Arlington, Va., coatimundi.

Fischer, Mrs. Milla, Washington, D.C., ocelot.

Fish and Wildlife Service, Boothbay Harbor, Maine, 6 double-crested cormorants, 6 gulls, 2 harbor seals. In cooperation with the Fish and Wildlife Service W. Widman, senior keeper at the National Zoological Park, collected at Kent Island, Eastern Shore, Md., 6 buffleheads, 4 black ducks, 3 pintails, 2 ring-necked ducks, 6 whistling swans; at Mills Island, Salisbury, Md., 4 American egrets, 4 Louisiana herons, 2 glossy ibises, 3 great white herons; and at Washington, N.C., 3 royal terns, 4 gray pelicans.

Garret, Col. E. W., Fort Leavenworth, Kans., night monkey.

Gray, Steven and Loraine, Bethesda, Md., black-and-red tamarin.

Hanson, Charles, Port Clinton, Ohio, massasauga, fox snake.

Harrls, Lester E., Takoma Park, Md., 14 timber rattlesnakes, hog-nosed snake, Harrison, Allen M., boa constrictor.

Hawes, Miss Elizabeth, Washington, D.C., 2 white-throated capuchins.

Isaac, Mrs. Lee, Arlington, Va., Formosan macaque.

Joy, J. E., St. Angelo, Texas, 5 diamond-back rattlesnakes, prairie rattlesnake.

Koltisko, Mrs. Frances M., Falls Church, Va., yellow-naped parrot.
 Kuntz, Dr. Robert E., Taipei, Taiwan, 2 pangolins, 2 Formosan ferret badgers,
 2 Formosan masked civets, 3 Formosan giant flying squirrels, 9 snorkel vipers.
 12 Formosan cobras, Pallas's sea eagle.
 Letner, George, Washington, D.C., 5 canaries, peach-faced lovebird.
 Munro, George, Calcutta, India, 2 sloth bears.
 O'Dunne, David, Baltimore, Md., woolly monkey.
 Palmer, Harold C., Atlanta, Ga., 2 Australian black snakes, tiger snake, brown
 snake, Australian copperhead, 4 carpet pythons, Australian monitor.
 Perz, Miss Louise, Sellersville, Pa., hill mynah.
 Royal Zoological Society, Amsterdam, Holland, 6 European cormorants.
 Salzman, Aaron, Alexandria, Va., blue-fronted parrot.
 Santos, John, Washington, D.C., 9 lineolated parrots, 14 cockatiels.
 Schmidt's Pet Shop, Washington, D.C., 12 jewelfishes, 38 "Jack Dempseys."
 Thomas, Charles, Washington, D.C., 2 European goldfinches, 4 European bull-
 finches, 4 slate-colored juncos, mockingbird.
 Tuck, Robert, Jr., Point of Rocks, Md., Cuban ground boa.
 Xanten, William, Jr., Washington, D.C., pygmy rattlesnake, mangrove water
 snake.

PURCHASES

Among important purchases of the year were a maned wolf from Argentina and a pair of black leopards. The collection of birds of prey was augmented by the receipt of a white-breasted Philippine sea eagle, black eagle, red-footed falcon, Lanner falcon, bearded vulture or lammergeyer, and two imperial eagles. Other purchases of interest were as follows:

2 pottos	2 white-faced mongooses
2 bush babies	2 zorillas
2 drills	4 crested rats
3 langur monkeys	black genet
African pangolin	3 hyrax
2 fennecs	3 California sea-lions
3 jackals	2 painted storks
2 yaks	Indian adjutant stork
3 sarus cranes	4 Cuban trogons
2 McBride's bustards	2 golden woodpeckers
2 starlings	8 crocodile birds
2 touracous	12 sunbirds
12 whydahs	3 ring-necked teal
3 Indian pygmy teals	10 Quaker parakeets
3 red-breasted geese	king cobra
2 Tokay geckos	Galapagos tortoise
2 ring-tailed genets	

EXCHANGES

By the judicious use of exchanges with other zoos and with individuals the following animals were obtained:

Alipore Zoo, Calcutta, India, 5 yellow monitors, 1 water monitor, 2 pythons, 5 wolf snakes, 3 greater ring-necked parakeets, 12 blossom-headed parakeets, 31 lesser ring-necked parakeets, 2 grey hornbills, 5 darters, 10 cotton teal, 2 peacock pheasants, 2 black-headed kaleeges, 12 emerald-winged doves.



1. A margay kitten, shown here with its mother, is the first ever born in the National Zoological Park. (Photograph by Arthur Ellis, *Washington Post*.)



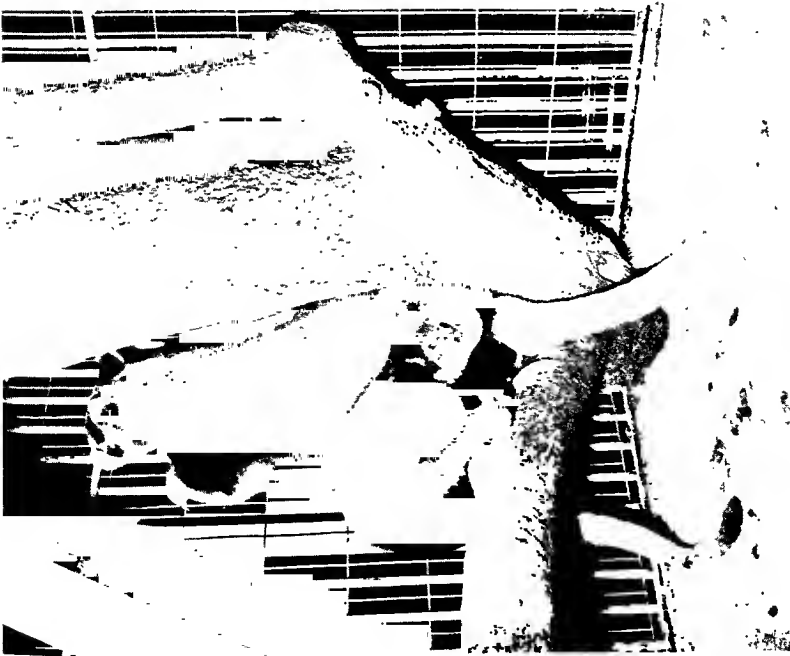
2. Maned wolf from the Argentine, a species not hitherto represented in the National Zoological Park for many years.



1. Indian rhinoceros, "Taram," shown here with Senior Keeper Charles Thomas, National Zoological Park.



2. A pair of *Oryx capensis*, gifts from the President of Tunisia to President Eisenhower's daughter-in-law. These graceful little antelopes are found in North Africa and Southwest Asia. National Zoological Park. (Photograph by Beall, *Washington Daily News*.)



1. Tree kangaroo with half grown young. These animals are a rich, glossy brown, with cream colored snout, jaws, and tail. National Zoological Park.



2. Presentation of baby African elephant to President Eisenhower on the White House lawn, October 12, 1959. Left to right: Wilbur Hale, supervisory keeper at the National Zoological Park; Dr. Jean Rjard, Associate Director of the Paris Zoo; L. Jean Grimmer, Associate Director of the National Zoological Park; President Eisenhower; Supervisory Keeper Cecil Gray. (Photograph by Randolph Rount, *Washington Evening Star*.)



1. Formal presentation of pygmy hippopotamus to National Zoological Park February 5, 1960. Left to right: Dr. Theodore Reed, Director of the National Zoological Park; Dr. Remington Kellogg, Assistant Secretary of the Smithsonian Institution; Francis A. Dennis, Liberian Chargé d'Affaires; Senior Keeper Charles Thomas.



The lammergeyer, or bearded vulture, is the largest European bird of prey. National Zoological Park. (Photograph by McNamee. *Washington Post*.)

Berlin Zoo, W. Germany, 2 striped African mongooses.
 Cleveland Zoo, Cleveland, Ohio, 6 black ducks.
 Crandon Park Zoo, Miami, Fla., 2 red-breasted teal.
 Deer Forest, Coloma, Mich., 2 aondads.
 Ellison, Robert J., Falls Church, Va., 3 desert lguanas, horned lizard, whip-tail lizard, desert tortoise.
 Hanson, Charles, Fort Clinton, Ohio, 4 Blanding's semi-box turtles, Butler's garter snake.
 Houston Zoo, Houston, Tex., 2 coral snakes, coach-whip snake, hog-nosed snake, indigo snake, bull snake, speckled snake.
 Meade, Richard, Hyattsville, Md., 2 Audubon's caracaras.
 New York Zoo, New York, N.Y., 2 boa constrictors, 2 Japanese water snakes, 2 anacondas, 2 puff adders, 2 mamushi (*Ancistrodon*).
 Payne, Mrs. Edward, College Park, Md., 2 saw-whet owls.
 Philadelphia Zoo, Philadelphia, Pa., 2 coscoroba swans, 2 ruddy sheldrakes, 2 South American sheldrakes, 2 Egyptian geese, 2 wood rails, black-faced ibis, long-eared owl.
 Quebec Zoo, Orsainville, Quebec, 6 evening grosbeaks, 2 white-capped sparrows.
 Riverside Park Zoo, Scottsbluff, Nebr., 2 golden eagles.
 Rochester Zoo, Rochester, N.Y., 3 silka deer.
 San Antonio Zoo, San Antonio, Tex., 5 reddish egrets, 4 cattle egrets, 6 roseate spoonbills, 2 roadrunners, ocellated turkey, 2 white-faced glossy ibises, 2 chachalacas, 2 cacomistles, 3 nine-banded armadillos.
 Washington Park Zoo, Portland, Oreg., Columbian ground squirrel, coyote, mountain beaver, 3 murre, raven, 6 Pacific rattlesnakes, 2 rubber boas, bullsnake.
 Zoorama, New Market, Va., guanaco, 2 fallow deer, peccary.

BIRTHS AND HATCHINGS

The number of young born in the Zoo was gratifying, although there were, as always, some disappointments. The pair of Pallas's cats, purchased last year, had young but did not raise them. The snow leopard, which had a cub two years ago that was successfully hand-raised, gave birth again, and this time the young was left with the mother and did not survive. For the first time in 30 years, timber wolves were born here, but none survived. On the other hand, a pair of margays had a kitten which the mother successfully raised, the first time for this Zoo. A hybrid macaque born in the Zoo is of interest because its sire was the famous Philippine macaque that in 1952 soared 37 miles into space encased in an Aerobee rocket shot from the Air Force Base at Holloman, N. Mex. It and a female (since deceased) were the first primates to reach such an altitude and survive.

Following the procedure of previous years, all births and hatchings are listed below, whether or not the young were successfully raised. In many instances the record of animals having bred in captivity is of importance. The tree kangaroo previously mentioned (p. 132) is included because, while it was not actually born here, the date of birth of kangaroos is customarily listed as the date when they are first observed in the pouch.

MAMMALS

Common name	Scientific name	Number
Rat kangaroo	<i>Potorous</i> sp.	2
Galago	<i>Galago crassicaudatus</i>	1
Potto	<i>Perodicticus potto</i>	1
Capuchin	<i>Cebus</i> sp.	1
Hybrid macaque	<i>Macaca philippensis</i> × <i>M. trus</i>	1
Barbary ape	<i>Macaca sylvanus</i>	1
Sooty mangabey	<i>Cercocebus fuliginosus</i>	1
DeBrazza's guenon	<i>Cercopithecus neglectus</i>	2
Chimpanzee	<i>Pan satyrus</i>	1
Two-toed sloth	<i>Choloepus didactylus</i>	3
Prairie dog	<i>Cynomys ludovicianus</i>	11
Flying squirrel	<i>Glaucomys volans</i>	3
Four-toed jerboa	<i>Allactaga tetradactyla</i>	1
Fat-tailed gerbil	<i>Pachyuromys duprasi</i>	3
African porcupine	<i>Hystrix galeata</i>	5
Dingo	<i>Canis antarcticus</i>	9
Timber wolf	<i>Canis lupus</i>	4
Cape hunting dog	<i>Lycan pictus</i>	6
European bear	<i>Ursus arctos</i>	2
Grizzly bear	<i>Ursus horribilis</i>	1
Hybrid bear	<i>Thalarcos maritimus</i> × <i>Ursus middendorfi</i>	1
Coatimundi	<i>Nasua narica</i>	1
Newman's genet	<i>Genetta genetta</i>	1
African water civet	<i>Atilax paludinosus</i>	2
Pallas's cat	<i>Felis manul</i>	1
Margay cat	<i>Felis wiedii tigrina</i>	1
Puma	<i>Felis concolor</i>	3
Eastern bobcat	<i>Lynx rufus</i>	3
Snow leopard	<i>Panthera uncia</i>	1
Grant's zebra	<i>Equus burchelli boehmi</i>	2
Llama	<i>Lama glama</i>	3
Brown fallow deer	<i>Dama dama</i>	4
White fallow deer		
Axis deer	<i>Axis axis</i>	2
Red deer	<i>Cervus elaphus</i>	3
Elk	<i>Cervus canadensis</i>	1
Sika deer	<i>Cervus nippon</i>	5
Virginia deer	<i>Odocoileus virginianus</i>	3
Reindeer	<i>Rangifer tarandus</i>	4
Sitatunga	<i>Tragelaphus speket</i>	1
Barbary sheep	<i>Ammotragus lervia</i>	3

BIRDS

Mute swan	<i>Cygnus olor</i>	3
Whooper swan	<i>Olor cygnus</i>	3
Canada goose	<i>Branta canadensis</i>	6

Common name	Scientific name	Number
Eider duck*-----	<i>Somateria mollissima</i> -----	3
Gadwall*-----	<i>Anas strepera</i> -----	5
European widgeon*-----	<i>Anas penelope</i> -----	5
Wood duck-----	<i>Aix sponsa</i> -----	36
Mandarin duck-----	<i>Dendroessa galericulata</i> -----	5
White-winged scoter-----	<i>Melanitta fusca deglandia</i> -----	1
Wild turkey-----	<i>Meleagris gallopavo</i> -----	6
Red junglefowl-----	<i>Gallus gallus</i> -----	8
Golden pheasant-----	<i>Chrysolophus pictus</i> -----	1
Kelp gull-----	<i>Larus dominicanus</i> -----	4

*Hatched from eggs imported from Iceland.

REPTILES

Slate water snake-----	<i>Enhydrys plumbea</i> -----	33
Florida water snake-----	<i>Natrix pictiventris</i> -----	26
Cottonmouth moccasin-----	<i>Ancistrodon piscivorus</i> -----	1
Massasauga-----	<i>Sistrurus catenatus</i> -----	5
Timber rattlesnake-----	<i>Crotalus horridus</i> -----	5
Snapping turtle-----	<i>Chelydra serpentina</i> -----	23
Mobile turtle-----	<i>Pseudemys elegans</i> -----	52
Painted turtle-----	<i>Chrysemys picta</i> -----	9
Red-bellied turtle-----	<i>Pseudemys rubriventris</i> -----	15

FISHES

White Cloud Mountain fish-----	<i>Tanichthys albonubes</i> -----	Many
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The importance of a zoological collection rests, to a large extent, upon the diversity and scope of its taxonomic representation throughout the whole of the Animal Kingdom. The National Zoological Park has enjoyed some measure of success in efforts to add representative species belonging to little-known or absent families.

The total number of accessions for the year was 1,312. This includes gifts, purchases, exchanges, deposits, births, and hatchings. Several minor species which are best displayed in large numbers do not have an individual count, merely being listed as "many."

STATUS OF THE COLLECTION

Class	Orders	Families	Species or subspecies	Individuals
Mammals-----	15	53	245	625+
Birds-----	21	80	362	1, 070+
Reptiles-----	4	23	176	484+
Amphibians-----	2	10	19	102+
Fish-----	4	8	19	114
Arthropods-----	3	3	3	Many
Mollusks-----	1	1	1	Many
Total-----	50	178	825	2, 395+

ANIMALS IN THE COLLECTION ON JUNE 30, 1960

MAMMALS

MONOTREMATA

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Tachyglossidae:		
Echidna, or spiny anteater-----	<i>Tachyglossus aculeatus</i> -----	1

MARSUPIALIA

Didelphidae:		
Opossum-----	<i>Didelphis marsupialis</i> -----	1
Dasyuridae:		
Tasmanian devil-----	<i>Sarcophilus harrisii</i> -----	1
Phalangeridae:		
Lesser flying phalanger-----	<i>Petaurus norfolcensis</i> -----	3
Phascolomidae:		
Hairy-nosed wombat-----	<i>Lasiiorhinus latifrons</i> -----	2
Mainland wombat-----	<i>Wombatus hirsutus</i> -----	1
Macropodidae:		
Rat kangaroo-----	<i>Potorous</i> sp-----	6
Ursine tree kangaroo-----	<i>Dendrolagus ursinus</i> -----	8

INSECTIVORA

Erinaceidae:		
European hedgehog-----	<i>Erinaceus europaeus</i> -----	1

PRIMATES

Lorisidae:		
Great galago-----	<i>Galago crassicaudatus</i> -----	2
Senegal galago-----	<i>Galago senegalensis</i> -----	3
Slow loris-----	<i>Nycticebus coucang</i> -----	1
Common potto-----	<i>Perodicticus potto</i> -----	2
Cebidae:		
Night monkey-----	<i>Aotus trivirgatus</i> -----	6
Red uakari-----	<i>Cacajao rubicundus</i> -----	1
Brown capuchin monkey	} <i>Cebus capucinus</i> -----	10
White-throated capuchin		
Capuchin		
Squirrel monkey-----	<i>Saimiri sciureus</i> -----	4
Colombian black spider monkey-----	<i>Ateles fusciceps</i> -----	1
Spider monkey-----	<i>Ateles geoffroyi</i> -----	2
Woolly monkey-----	<i>Lagothrix pygmaea</i> -----	2
Callithricidae:		
Cottontop marmoset-----	<i>Callithrix jacchus</i> -----	1
Black-and-red tamarin-----	<i>Saquinus nigricollis</i> -----	1
Cercopithecidae:		
Toque, or bonnet monkey-----	<i>Macaca sinica</i> -----	8
Javan macaque-----	<i>Macaca irus mordax</i> -----	2
Crab-eating macaque-----	<i>Macaca irus</i> -----	1
Philippine macaque-----	<i>Macaca philippinensis</i> -----	2
Macaque hybrid-----	<i>Macaca philippinensis</i> X <i>Macaca irus</i> -----	1

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Cercopithecidae—Continued		
Rhesus monkey-----	<i>Macaca mulatta</i> -----	4
Formosan monkey-----	<i>Macaca cyclopis</i> -----	2
Red-faced macaque-----	<i>Macaca speciosa</i> -----	1
Barbary ape-----	<i>Macaca sylvanus</i> -----	12
Moor macaque-----	<i>Macaca maurus</i> -----	1
Gray-cheeked mangabey-----	<i>Cercocebus albigena</i> -----	1
Agile mangabey-----	<i>Cercocebus galeritus agilis</i> -----	1
Golden-bellied mangabey-----	<i>Cercocebus galeritus</i> <i>chrysogaster</i> -----	1
Red-crowned mangabey-----	<i>Cercocebus torquatus</i> -----	1
Sooty mangabey-----	<i>Cercocebus fuliginosus</i> -----	5
Crested mangabey-----	<i>Cercocebus aterrimus</i> <i>opdenboschii</i> -----	2
Black-crested mangabey-----	<i>Cercocebus aterrimus</i> -----	3
Hamadryas baboon-----	<i>Papio hamadryas</i> -----	1
Chacma baboon-----	<i>Papio comatus</i> -----	1
Mandrill-----	<i>Mandrillus sphinx</i> -----	1
Gelada baboon-----	<i>Theropithecus gelada</i> -----	1
Vervet guenon-----	<i>Cercopithecus aethiops</i> <i>pygerythrus</i> -----	1
Green guenon-----	<i>Cercopithecus aethiops</i> <i>sabaeus</i> -----	2
Guenon, hybrid-----	<i>Cercopithecus aethiops</i> X <i>C.a.</i> <i>pygerythrus</i> -----	2
Moustached monkey-----	<i>Cercopithecus cephus</i> -----	2
Diana monkey-----	<i>Cercopithecus diana</i> -----	1
Preussi's guenon-----	<i>Cercopithecus lhoesti preussi</i> -----	1
DeBrazza's guenon-----	<i>Cercopithecus neglectus</i> -----	3
White-nosed guenon-----	<i>Cercopithecus nictitans</i> -----	1
Lesser white-nosed guenon-----	<i>Cercopithecus nictitans</i> <i>petaurista</i> -----	1
Allen's monkey-----	<i>Allenopithecus nigroviridis</i> -----	2
Spectacled, or Phayre's langur-----	<i>Presbytis phayrei</i> -----	1
Entellus monkey-----	<i>Presbytis entellus</i> -----	2
Pongidae:		
White-handed gibbon-----	<i>Hylobates lar</i> -----	6
Wau-wau gibbon-----	<i>Hylobates moloch</i> -----	1
Gibbon, hybrid-----	<i>Hylobates agilis</i> X <i>H. lar</i> <i>pileatus</i> -----	1
Gibbon, hybrid-----	<i>Hylobates lar</i> X <i>H. sp.</i> -----	2
Sumatran orangutan-----	<i>Pongo pygmaeus</i> -----	2
Bornean orangutan-----	<i>Pongo pygmaeus abelii</i> -----	1
Chimpanzee-----	<i>Pan satyrus</i> -----	4
Gorilla-----	<i>Gorilla gorilla</i> -----	2

EDENTATA

Myrmecophagidae:		
Giant anteater-----	<i>Myrmecophaga tridactyla</i> -----	1
Bradypodidae:		
Two-toed sloth-----	<i>Choloepus didactylus</i> -----	6
Dasypodidae:		
Nine-banded armadillo-----	<i>Dasypus novemcinctus</i> -----	3

PHOLIDOTA

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Manidae:		
Giant pangolin.....	<i>Manis temminckii</i>	1

LAGOMORPHA

Leporidae:		
Domestic rabbit.....	<i>Oryctolagus cuniculus</i>	4
Jack rabbit.....	<i>Lepus californicus melanotis</i> ---	1

RODENTIA

Aplodontidae:		
Mountain beaver.....	<i>Aplodontia rufa</i>	1
Sciuridae:		
Gray squirrel (black).....	<i>Sciurus carolinensis</i> , melanistic phase.....	2
Gray squirrel (albino).....	<i>Sciurus carolinensis</i>	2
Fox squirrel.....	<i>Sciurus niger</i>	1
Columbian ground squirrel.....	<i>Citellus columbianus</i>	1
White-tailed antelope ground squirrel rel	<i>Citellus leucurus</i>	1
Giant Indian squirrel.....	<i>Ratufa indica</i>	3
Asiatic squirrel.....	<i>Callosciurus nigrovittatus</i>	1
Formosan tree squirrel.....	<i>Callosciurus erythraeus</i>	5
Asiatic forest squirrel.....	<i>Callosciurus caniceps</i>	3
Striped ground squirrel.....	<i>Lariscus insignis</i>	1
Long-nosed squirrel.....	<i>Dremomys rufigenis</i>	1
Woodchuck, or groundhog.....	<i>Marmota monax</i>	2
Prairie dog.....	<i>Cynomys ludovicianus</i>	Many
Eastern chipmunk.....	<i>Tamias striatus</i>	1
Eastern chipmunk (albino).....	<i>Tamias striatus</i>	1
Formosan flying squirrel.....	<i>Petaurista grandis</i>	2
Eastern flying squirrel.....	<i>Glaucomys volans volans</i>	16
Cricetidae:		
Hamster	<i>Mesocricetus auratus</i>	3
Vesper rat.....	<i>Nyctomys sumichrasti</i>	1
White-footed mouse.....	<i>Peromyscus</i> sp.....	2
Pine vole.....	<i>Pitymys pinetorum</i>	1
Muskrat	<i>Ondatra zibethicus</i>	1
Gerbil	<i>Gerbillus pyramidum</i>	2
Lesser Egyptian gerbil.....	<i>Gerbillus gerbillus</i>	1
Fat-tail gerbil.....	<i>Pachyuromys duprasi</i>	19
Hairy-tailed jird.....	<i>Sekeetamys calurus</i>	1
Jird	<i>Meriones</i> sp.....	12
Jird	<i>Meriones</i> sp.....	2
Muridae:		
Egyptian spiny mouse.....	<i>Acomys cahirinus</i>	10
Egyptian spiny mouse.....	<i>Acomys dimidiatus</i>	Many
Multimammate mouse.....	<i>Mastomys</i> sp.....	2
Crested rat.....	<i>Lophiomyys</i> sp.....	4
Slender-tailed cloud rat.....	<i>Phloeomys cumingii</i>	1
Gliridae:		
African dormouse.....	<i>Graphiurus murinus</i>	1

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Dipodidae:		
Lesser, or desert, jerboa-----	<i>Jaculus jaculus</i> -----	1
Hystriidae:		
Malay porcupine-----	<i>Acanthion brachyura</i> -----	1
African porcupine-----	<i>Hystrix galeata</i> -----	10
Erethizontidae:		
Prehensile-tailed porcupine-----	<i>Coendou prehensilis</i> -----	1
Caviidae:		
Guinea-pig-----	<i>Cavia porcellus</i> -----	6
Hydrochoeridae:		
Capybara-----	<i>Hydrochoerus hydrochoeris</i> -----	1
Dinomyidae:		
Red agouti-----	<i>Dinomys branickii</i> -----	1
Chinchillidae:		
Chinchilla-----	<i>Chinchilla chinchilla</i> -----	2
Peruvian viscaccia-----	<i>Lagidium viscaccia</i> -----	1

CARNIVORA

Canidae:		
Dingo-----	<i>Canis antarcticus</i> -----	3
Coyote-----	<i>Canis latrans</i> -----	1
Black-backed jackal-----	<i>Canis mesomelas</i> -----	3
Timber wolf-----	<i>Canis lupus nubilus</i> -----	2
Texas red wolf-----	<i>Canis niger rufus</i> -----	2
Red fox-----	<i>Vulpes fulva</i> -----	1
Platinum fox-----	<i>Vulpes fulva</i> -----	2
Fennec-----	<i>Fennecus zerda</i> -----	2
Gray fox-----	<i>Urocyon cinereoargenteus</i> -----	1
Big-eared fox-----	<i>Otocyon megalotis</i> -----	2
Raccoon dog-----	<i>Nyctereutes procyonoides</i> -----	1
Maned wolf-----	<i>Chrysocyon jubatus</i> -----	1
Cape hunting dog-----	<i>Lycan pictus</i> -----	3
Ursidae:		
Spectacled bear-----	<i>Tremarctos ornatus</i> -----	1
Himalayan bear-----	<i>Selenarctos thibetanus thibetanus</i> -----	2
Japanese black bear-----	<i>Selenarctos thibetanus japonicus</i> -----	1
Korean bear-----	<i>Selenarctos thibetanus ussuriensis</i> -----	2
Black bear-----	<i>Euarctos americanus</i> -----	2
Alaskan brown bear-----	<i>Ursus sp</i> -----	1
European brown bear-----	<i>Ursus arctos</i> -----	3
Iranian brown bear-----	<i>Ursus arctos occidentalis</i> -----	2
Alaskan Peninsula bear-----	<i>Ursus gyas</i> -----	2
Grizzly bear-----	<i>Ursus horribilis</i> -----	2
Sitka brown bear-----	<i>Ursus sitkensis</i> -----	2
Polar bear-----	<i>Thalarctos maritimus</i> -----	2
Hybrid bear-----	<i>Thalarctos maritimus</i> X <i>Ursus middendorffi</i> -----	4
Malay sun bear-----	<i>Helarctos malayanus</i> -----	3
Sloth bear-----	<i>Melursus ursinus</i> -----	2

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Procyonidae:		
Raccoon.....	<i>Procyon lotor</i>	9
Red coatimundi.....	<i>Nasua nasua</i>	1
Coatimundi.....	<i>Nasua narica</i>	5
Cacomistle, or Ring-tailed cat.....	<i>Bassariscus astutus</i>	2
Kinkajou.....	<i>Potos flavus</i>	4
Olingo.....	<i>Bassaricyon gabbi</i>	2
Lesser panda.....	<i>Ailurus fulgens</i>	6
Mustelidae:		
Black-footed ferret.....	<i>Mustela nigripes</i>	1
Short-tailed weasel.....	<i>Mustela erminea</i>	1
Marten.....	<i>Martes americana</i>	1
Fisher.....	<i>Martes pennanti</i>	1
Tayra.....	<i>Eira barbara</i>	1
Grison.....	<i>Galictis vittata</i>	1
Zorilla, or Striped weasel.....	<i>Ictonyx capensis</i>	2
Wolverine.....	<i>Gulo luscus</i>	1
American badger.....	<i>Taxidea taxus</i>	1
Golden-bellied ferret-badger.....	<i>Helictis moschata subaurantiaca</i>	5
Common skunk.....	<i>Mephitis mephitis</i>	4
California spotted skunk.....	<i>Spilogale putorius phenax</i>	1
African small-clawed otter.....	<i>Lutra cinerea</i>	1
South American flat-tailed otter.....	<i>Pteronura brasiliensis</i>	1
Malayan small-clawed otter.....	<i>Amblonyx cinerea</i>	1
Viverridae:		
Genet.....	<i>Genetta genetta neumanni</i>	6
Genet (black phase).....	<i>Genetta genetta neumanni</i>	1
Formosan spotted civet.....	<i>Viverricula indica</i>	2
Ground civet.....	<i>Viverra zibetha</i>	1
Linsang.....	<i>Prionodon linsang</i>	1
African palm civet.....	<i>Nandinia binotata</i>	1
Formosan masked civet.....	<i>Paguma larvata taiwana</i>	3
Binturong.....	<i>Arctictis binturong</i>	1
African gray mongoose.....	<i>Herpestes ichneumon</i>	1
White-faced mongoose.....	<i>Edeogale sp.</i>	2
African water civet.....	<i>Atilax paludinosus</i>	4
Striped African mongoose.....	<i>Crossarchus fasciatus</i>	2
White-tailed civet.....	<i>Ichneumia albicauda</i>	2
Cryptoproctidae:		
Fossa.....	<i>Cryptoprocta ferox</i>	1
Hyaenidae:		
Striped hyena.....	<i>Hyaena hyaena</i>	2
Spotted hyena.....	<i>Crocuta crocuta germinans</i>	1
Felidae:		
Jungle cat.....	<i>Felis chaus</i>	1
Pallas's cat.....	<i>Felis manul</i>	2
Serval cat.....	<i>Felis serval</i>	3
Ocelot.....	<i>Felis pardalis</i>	2
Margay cat.....	<i>Felis wiedii tigrina</i>	3
Puma.....	<i>Felis concolor</i>	4
Lynx.....	<i>Lynx canadensis</i>	1

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Felidae—Continued		
Bobcat.....	<i>Lynx rufus</i>	3
Leopard.....	<i>Panthera pardus</i>	5
Black leopard.....	<i>Panthera pardus</i>	3
Lion.....	<i>Panthera leo</i>	3
Bengal tiger.....	<i>Panthera tigris</i>	3
Jaguar.....	<i>Panthera onca</i>	1
Snow leopard.....	<i>Panthera uncia</i>	3
Cheetah.....	<i>Acinonyx jubata</i>	2

PINNIPEDIA

Otariidae:		
California sea-lion.....	<i>Zalophus californianus</i>	5
Patagonian sea-lion.....	<i>Otaria flavescens</i>	1

TUBULIDENTATA

Orycteropodidae:		
Aardvark, or antbear.....	<i>Orycteropus afer</i>	1

PROBOSCIDEA

Elephantidae:		
African elephant.....	<i>Loxodonta africana</i>	2
Indian elephant.....	<i>Elephas maximus</i>	1

HYRACOIDEA

Procaviidae:		
Hyrax.....	<i>Procavia syriaca</i>	1

PERISSODACTYLA

Equidae:		
Mongolian wild horse.....	<i>Equus przewalskii</i>	1
Kiang, or Asiatic wild ass.....	<i>Equus kiang</i>	1
Burro, or donkey.....	<i>Equus asinus</i>	1
Grant's zebra.....	<i>Equus burchelli boehmi</i>	3
Grevy's zebra.....	<i>Equus grevyi</i>	3

Tapiridae:		
Brazilian tapir.....	<i>Tapirus terrestris</i>	1

Rhinocerotidae:		
Great one-horned Indian rhinoceros.....	<i>Rhinoceros unicornis</i>	1
White, or square-lipped, rhinoceros.....	<i>Ceratotherium simum</i>	2

ARTIODACTYLA

Tayassuidae:		
Collared peccary.....	<i>Pecari tajacu</i>	4

Hippopotamidae:		
Hippopotamus.....	<i>Hippopotamus amphibius</i>	3
Pygmy hippopotamus.....	<i>Choeropsis liberiensis</i>	4

Camelidae:		
Llama.....	<i>Lama glama</i>	6
Guanaco.....	<i>Lama glama guanicoe</i>	3
Alpaca.....	<i>Lama pacos</i>	4
Bactrian camel.....	<i>Camelus bactrianus</i>	2

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Cervidae:		
Brown fallow deer.....	<i>Dama dama</i>	11
White fallow deer.....	<i>Dama dama</i>	9
Axis deer.....	<i>Axis axis</i>	4
Red deer.....	<i>Cervus elaphus</i>	7
American elk.....	<i>Cervus canadensis</i>	5
Sika deer.....	<i>Cervus nippon</i>	9
Père David's deer.....	<i>Elaphurus davidianus</i>	1
Virginia deer.....	<i>Odocoileus virginianus</i>	9
Reindeer.....	<i>Rangifer tarandus</i>	13
Forest caribou.....	<i>Rangifer caribou</i>	1
Giraffidae:		
Okapi.....	<i>Okapia johnstoni</i>	1
Nubian giraffe.....	<i>Giraffa camelopardalis</i>	3
Antilocapridae:		
Pronghorn.....	<i>Antilocapra americana</i>	5
Bovidae:		
Sitatunga.....	<i>Tragelaphus spekii</i>	2
Eland.....	<i>Taurotragus oryx</i>	2
Anoa.....	<i>Anoa depressicornis</i>	2
Zebu.....	<i>Bos indicus</i>	1
Yak.....	<i>Poephagus grunniens</i>	4
Gaur.....	<i>Bibos gaurus</i>	3
African buffalo.....	<i>Syncerus caffer</i>	1
American bison.....	<i>Bison bison</i>	2
Wisent, or European bison.....	<i>Bison bonasus</i>	2
Dorcas gazelle.....	<i>Gazella dorcas</i>	2
Rocky Mountain goat.....	<i>Oreamnos americanus</i>	2
Tahr.....	<i>Hemitragus jemlahicus</i>	1
Ibex.....	<i>Capra ibex</i>	1
Blue sheep.....	<i>Pseudois nayaur</i>	1
Aoudad.....	<i>Ammotragus lervia</i>	5
Dall sheep.....	<i>Ovis dalli</i>	2

BIRDS

SPHENISCIFORMES

Spheniscidae:

King penguin.....	<i>Aptenodytes patagonica</i>	4
Adélie penguin.....	<i>Pygoscelis adeliae</i>	5

STRUTHIONIFORMES

Struthionidae:

Ostrich.....	<i>Struthio camelus</i>	1
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RHEIFORMES

Rheidae:

Rhea.....	<i>Rhea americana</i>	1
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CASUARIIFORMES

Casuaridae:

Cassowary.....	<i>Casuarius</i> sp.....	2
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Dromicidae:

Emu.....	<i>Dromictus novaehollandiae</i>	4
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PROCELLARIIFORMES

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Diomedidae:		
Black-footed albatross.....	<i>Diomedea nigripes</i>	2
Laysan albatross.....	<i>Diomedea immutabilis</i>	1

PELECANIFORMES

Pelecanidae:		
Rose-colored pelican.....	<i>Pelecanus onocrotalus</i>	2
White pelican.....	<i>Pelecanus erythrorhynchus</i>	3
Brown pelican.....	<i>Pelecanus occidentalis</i>	5
Phalacrocoracidae:		
Double-crested cormorant.....	<i>Phalacrocorax auritus</i>	4
European cormorant.....	<i>Phalacrocorax carbo</i>	6
Anhingidae:		
Indian darter.....	<i>Plotus melanogaster</i>	3

CICONIIFORMES

Ardeidae:		
Reddish egret.....	<i>Dichromanassa rufescens</i>	4
Reddish egret (white phase).....	<i>Dichromanassa rufescens</i>	1
Cattle egret.....	<i>Bubulcus ibis</i>	4
American egret.....	<i>Casmerodius albus</i>	1
Snowy egret.....	<i>Leucophoyx thula</i>	2
Great white heron.....	<i>Ardea occidentalis</i>	2
Louisiana heron.....	<i>Hydranassa tricolor</i>	3
Black-crowned night heron.....	<i>Nycticorax nycticorax</i>	12
Little blue heron.....	<i>Florida caerula</i>	1
Least bittern.....	<i>Ixobrychus exilis</i>	1
Tiger bittern.....	<i>Tigrisoma lineatum</i>	3
Cochleariidae:		
Boat-billed heron.....	<i>Cochlearius cochlearius</i>	1
Balaenicipitidae:		
Shoebill.....	<i>Balaeniceps rex</i>	1
Ciconiidae:		
Indian adjutant stork.....	<i>Leptoptilos dubius</i>	1
White-bellied stork.....	<i>Abdimia sphenorhyncha</i>	2
Threskiornithidae:		
White ibis.....	<i>Eudocimus albus</i>	2
Scarlet ibis.....	<i>Eudocimus ruber</i>	2
Black-faced ibis.....	<i>Theristicus melanopis</i>	1
Black-headed ibis.....	<i>Threskiornis melanocephala</i>	1
White-faced glossy ibis.....	<i>Plegadis mexicana</i>	2
Eastern glossy ibis.....	<i>Plegadis falcinellus</i>	2
Roseate spoonbill.....	<i>Ajaia ajaia</i>	8
Phoenicopteridae:		
Chilean flamingo.....	<i>Phoenicopiterus chilensis</i>	2
Cuban flamingo.....	<i>Phoenicopiterus ruber</i>	1
Old World flamingo.....	<i>Phoenicopiterus antiquorum</i>	1

ANSERIFORMES

Anhimidae:		
Crested screamer.....	<i>Chauna torquata</i>	4

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Anatidae:		
Coscoroba swan.....	<i>Coscoroba coscoroba</i>	2
Mute swan.....	<i>Ocygnus olor</i>	5
Whooper swan.....	<i>Olor cygnus</i>	2
Whistling swan.....	<i>Olor columbianus</i>	7
Trumpeter swan.....	<i>Olor buccinator</i>	2
Black swan.....	<i>Chenopsis atrata</i>	3
Egyptian goose.....	<i>Alopochen aegyptiacus</i>	2
White-fronted goose.....	<i>Anser albifrons</i>	3
Indian bar-headed goose.....	<i>Eulabia indica</i>	5
Emperor goose.....	<i>Philacte canagica</i>	2
Blue goose.....	<i>Chen caerulescens</i>	6
Lesser snow goose.....	<i>Chen hyperborea hyperborea</i>	2
Greater snow goose.....	<i>Chen hyperborea atlantica</i>	5
Ross's goose.....	<i>Chen rossii</i>	4
Red-breasted goose.....	<i>Branta ruficollis</i>	2
Canada goose.....	<i>Branta canadensis</i>	30
Lesser Canada goose.....		
Cackling goose.....		
White-cheeked goose.....	<i>Branta canadensis</i> × <i>Chen</i> <i>caerulescens</i>	2
Canada goose × blue goose, hybrid.....		
Wood duck.....	<i>Aix sponsa</i>	Many
Wood duck × Red-headed duck, hybrid.....	<i>Aix sponsa</i> × <i>Aythya americana</i>	1
Pintail duck.....	<i>Anas acuta</i>	4
Chestnut-breasted teal.....	<i>Anas castanea</i>	2
Ringed, or ring-necked, teal.....	<i>Anas leucophrys</i>	3
Gadwall.....	<i>Anas strepera</i>	5
European wigeon.....	<i>Anas penelope</i>	5
Mallard duck.....	<i>Anas platyrhynchos</i>	19
Mallard duck, albino.....	<i>Anas platyrhynchos</i>	1
Mallard duck × American pintail duck, hybrid.....	<i>Anas platyrhynchos</i> × <i>Anas</i> <i>acuta</i>	1
Indiano spotted-bill duck.....	<i>Anas pocillorhyncha</i>	1
Black duck.....	<i>Anas rubripes</i>	11
Greater scaup duck.....	<i>Aythya marila</i>	7
Lesser scaup duck.....	<i>Aythya affinis</i>	5
Red-headed duck.....	<i>Aythya americana</i>	10
Ring-necked duck.....	<i>Aythya collaris</i>	2
Canvasback duck.....	<i>Aythya valisineria</i>	7
Bufflehead duck.....	<i>Bucephala albeola</i>	3
Black-bellied tree duck.....	<i>Dendrocygna autumnalis</i>	8
Fulvous tree duck.....	<i>Dendrocygna bicolor</i>	1
Mandarin duck.....	<i>Dendrocygna galeaticulata</i>	10
Baldpate.....	<i>Mareca americana</i>	13
American white-winged scoter.....	<i>Melanitta fusca deglandi</i>	1
Rosy-billed pochard.....	<i>Melanitta perspicillata</i>	1
Red-crested pochard.....	<i>Nettion rufina</i>	1
Cotton teal.....	<i>Nettion coromandelianus</i>	10
Comb duck.....	<i>Sarkidiornis melanotos</i>	1
Northern eider duck.....	<i>Somateria mollissima borealis</i>	2

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Anatidae—Continued		
American eider duck.....	<i>Somateria mollissima dresseri</i>	2
South American shelldrake.....	<i>Casarca cana</i>	2
Ruddy shelldrake.....	<i>Casarca ferruginea</i>	2
European shell duck.....	<i>Tadorna tadorna</i>	1

FALCONIFORMES

Cathartidae:

Andean condor.....	<i>Vultur gryphus</i>	1
King vulture.....	<i>Sarcoramphus papa</i>	1
Black vulture.....	<i>Coragyps atratus</i>	6
White-backed vulture.....	<i>Pseudogyps africanus</i>	1
Ruppell's vulture.....	<i>Gyps rueppellii</i>	3
Turkey vulture.....	<i>Cathartes aura</i>	9

Sagittaridae:

Secretarybird.....	<i>Sagittarius serpentarius</i>	2
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Accipitridae:

African yellow-billed kite.....	<i>Milvus migrans</i>	2
Brahminy kite.....	<i>Haliaeetus indus</i>	1
Black-faced hawk.....	<i>Leucopternis melanops</i>	1
Red-tailed hawk.....	<i>Buteo jamaicensis</i>	3
Swainson's hawk.....	<i>Buteo swainsoni</i>	1
Great black hawk.....	<i>Ictinaetus malayensis</i>	1
Crane hawk, or red-footed falcon.....	<i>Falco vespertinus</i>	1
Golden eagle.....	<i>Aquila chrysaetos</i>	3
Imperial eagle.....	<i>Aquila heliaca</i>	2
White-breasted Philippine sea eagle.....	<i>Haliaeetus leucogaster</i>	1
Pallas's sea eagle.....	<i>Haliaeetus leucoryphus</i>	1
Bald eagle.....	<i>Haliaeetus leucocephalus</i>	5
Buzzard eagle.....	<i>Buteo borealis</i>	1
Harpy eagle.....	<i>Harpia harpyja</i>	1
Guianan crested eagle.....	<i>Morphnus guianensis</i>	1
Monkey-eating eagle.....	<i>Pitheophaga jefferyi</i>	1
Bateleur eagle.....	<i>Terathopus ecaudatus</i>	3
Bearded vulture.....	<i>Gypactus barbatus</i>	1

Pandionidae:

American osprey.....	<i>Pandion haliaetus carolinensis</i>	2
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Falconidae:

Large-billed, or lanner, falcon.....	<i>Falco biarmicus</i>	1
Sparrow hawk.....	<i>Falco sparverius</i>	5
Duck hawk.....	<i>Falco peregrinus anatum</i>	1
Forest falcon.....	<i>Micrastur semitorquatus</i>	2
Chimango.....	<i>Milvago chimango</i>	2
Audubon's caracara.....	<i>Polyborus cheriway</i>	3
South American caracara.....	<i>Polyborus plancus</i>	3

GALLIFORMES

Megapodidae:

Brush turkey.....	<i>Alectura lathamii</i>	1
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Cracidae:

Blue-cered curassow.....	<i>Crax alberti</i>	1
Wattled curassow.....	<i>Crax globulosa</i>	2
Panama curassow.....	<i>Crax panamensis</i>	1
Nocturnal curassow.....	<i>Nothocrax urumutum</i>	1

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Cracidae—Continued		
Chachalaca.....	<i>Ortalis vetula mecalli</i>	2
White-headed piping guan.....	<i>Pipile cumanensis</i>	1
Phasianidae:		
Erckel's francolin.....	<i>Francolinus erckeli</i>	2
Hildebrandt's francolin.....	<i>Francolinus hildebrandti</i>	1
Bob-white.....	<i>Colinus virginianus</i>	4
Japanese quail.....	<i>Coturnix coturnix</i>	1
Argus pheasant.....	<i>Argusianus argus</i>	1
Golden pheasant.....	<i>Chrysolophus pictus</i>	3
Red junglefowl.....	<i>Gallus gallus</i>	13
Nepal pheasant.....	<i>Gennaeus leucomelanus</i>	4
Black-backed kaleege pheasant.....	<i>Gennaeus melanonotus</i>	2
Peafowl.....	<i>Pavo cristatus</i>	13
Ring-necked pheasant.....	<i>Phasianus colchicus</i>	4
Ring-necked pheasant, albino.....	<i>Phasianus colchicus</i>	1
Bhutan, or gray peacock pheasant.....	<i>Polyplectron bicalcaratum</i>	2
Reeves's pheasant.....	<i>Syrmaticus reevesi</i>	2
Numididae:		
Vulturine guineafowl.....	<i>Acryllium vulturinum</i>	4
Meleagrididae:		
Ocellated turkey.....	<i>Agriocharis ocellata</i>	2
Wild turkey.....	<i>Meleagris gallopavo</i>	8
GRUIFORMES		
Gruidae:		
Siberian crane.....	<i>Grus leucogeranus</i>	1
Demolselle crane.....	<i>Anthropoides virgo</i>	1
Sarus crane.....	<i>Antigone antigone</i>	2
Psophiidae:		
Trumpeter.....	<i>Psophia crepitans</i>	2
Rallidae:		
Cayenne wood rail.....	<i>Aramides cajanea</i>	2
Virginia rail.....	<i>Rallus limicola</i>	1
South Pacific swamp-hen.....	<i>Porphyrio poliocephalus</i>	1
American coot.....	<i>Fulica americana</i>	1
Eurypygidae:		
Sun blttern.....	<i>Eurypyga helias</i>	1
Cariamidae:		
Cariama, or seriama.....	<i>Cariama cristata</i>	1
Otididae:		
McBride's bustard.....	<i>Otis tetraz</i>	2
CHARADRIIFORMES		
Jacanidae:		
Common jacana.....	<i>Jacana spinosa</i>	3
Haematopodidae:		
Oystercatcher.....	<i>Haematopus ostralegus</i>	2
Charadriidae:		
Golden plover.....	<i>Charadrius apricarius</i>	2
Australian banded plover.....	<i>Zonifer tricolor</i>	6
South American lapwing.....	<i>Belonopterus cayennensis</i>	2
Killdeer.....	<i>Charadrius vociferus</i>	1
Crocodile bird.....	<i>Pluvianus aegyptus</i>	7

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Scolopacidae:		
Pectoral sandpiper.....	<i>Erolia melanotos</i>	1
Recurvirostridae:		
Black-necked stilt.....	<i>Himantopus mexicanus</i>	1
Burhinidae:		
South American thick-knee.....	<i>Burhinus bistriatus</i>	1
Stercorariidae:		
MacCormick's skua.....	<i>Catharacta maccormicki</i>	4
Laridae:		
Ring-billed gull.....	<i>Larus delawarensis</i>	3
Kelp gull.....	<i>Larus dominicanus</i>	5
Laughing gull.....	<i>Larus atricilla</i>	1
Herring gull.....	<i>Larus argentatus</i>	3
Great black-backed gull.....	<i>Larus marinus</i>	1
Silver gull.....	<i>Larus novaehollandiae</i>	8
Royal tern.....	<i>Thalasseus maximus</i>	2
Alcidae:		
Atlantic, or common, murre.....	<i>Uria aalge</i>	2

COLUMBIFORMES

Columbidae:		
Band-tailed pigeons.....	<i>Columba fasciata</i>	2
High-flying Budapest pigeon.....	<i>Columba livia</i>	1
Black-billed pigeon.....	<i>Columba nigristrois</i>	1
Crowned pigeon.....	<i>Goura victoria</i>	2
Indian emerald-winged tree dove.....	<i>Chalcophaps indica</i>	11
Bleeding-heart dove.....	<i>Gallicolumba luzonica</i>	2
Diamond dove.....	<i>Geopelia cuneata</i>	1
Plain-breasted ground dove.....	<i>Columbigallina minuta</i>	6
Ground dove.....	<i>Columbigallina passerina</i>	5
Ring-necked dove.....	<i>Streptopelia decaocto</i>	7
Blue-headed ring dove.....	<i>Streptopelia tranquebarica</i>	2
White-winged dove.....	<i>Zenaida asiatica</i>	1
Mourning dove.....	<i>Zenaidura macroura</i>	3

PSITTACIFORMES

Psittacidae:		
Kea parrot.....	<i>Nestor notabilis</i>	2
Red lory.....	<i>Domicella garrula</i>	1
Banksian cockatoo.....	<i>Calyptorhynchus magnificus</i>	1
White cockatoo.....	<i>Kakatoe alba</i>	2
Solomon Islands cockatoo.....	<i>Kakatoe duerops</i>	1
Sulphur-crested cockatoo.....	<i>Kakatoe galerita</i>	4
Bare-eyed cockatoo.....	<i>Kakatoe sanguinea</i>	5
Great red-crested cockatoo.....	<i>Kakatoe moluccensis</i>	1
Leadbeater's cockatoo.....	<i>Kakatoe leadbeateri</i>	7
Cockatiel.....	<i>Nymphicus hollandicus</i>	15
Yellow-and-blue macaw.....	<i>Ara araurauna</i>	3
Red-and-blue macaw.....	<i>Ara chloroptera</i>	3
Red-blue-and-yellow macaw.....	<i>Ara macao</i>	2
Petz's parakeet.....	<i>Aratinga canicularis</i>	1
Rusty-cheeked parrot.....	<i>Aratinga pertinax</i>	2

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Psittacidae—Continued		
Yellow-naped parrot.....	<i>Amazona auropalliata</i>	5
Finsch's parrot.....	<i>Amazona finschi</i>	1
Blue-fronted parrot.....	<i>Amazona aestiva</i>	1
Red-fronted parrot.....	<i>Amazona bodini</i>	1
Double yellow-headed parrot.....	<i>Amazona oratrix</i>	3
Lineolated parakeet.....	<i>Bolborhynchus lineolatus</i>	7
White-winged parakeet.....	<i>Brotogeris versicolurus</i>	1
Blossom-headed parakeet.....	<i>Psittacula cyanocephala</i>	12
Greater ring-necked parakeet.....	<i>Psittacula eupatria</i>	3
Rose-breasted parakeet.....	<i>Psittacula alexandri</i>	1
Lesser ring-necked parakeet.....	<i>Psittacula krameri</i>	6
Barraband's parakeet.....	<i>Polytelis sacainsoni</i>	1
Quaker parakeet.....	<i>Myopsittacus monachus</i>	20
Budgerigar, or grass parakeet.....	<i>Melopsittacus undulatus</i>	Many
Rosy-faced lovebird.....	<i>Agapornis roseicollis</i>	1
Masked lovebird.....	<i>Agapornis personata</i>	2
Yellow-thighed eaique.....	<i>Pionites leucogaster xantho-</i> <i>meria</i>	1

CUCULIFORMES

Musophagidae:

Purple touraco.....	<i>Tauraco persa</i>	1
South African touraco.....	<i>Tauraco corythair</i>	2
White-bellied go-away-bird.....	<i>Corythairoides leucogaster</i>	1
Plantain-eater.....	<i>Crinifer africanus</i>	1

Cuculidae:

Koel.....	<i>Eudynamis scolopacea</i>	1
Roadrunner.....	<i>Geococcyx californianus</i>	3

STRIGIFORMES

Tytonidae:

Barn owl.....	<i>Tyto alba</i>	1
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Strigidae:

Great horned owl.....	<i>Bubo virginianus</i>	6
Screech owl.....	<i>Otus asio</i>	3
Spectacled owl.....	<i>Pulsatrix perspicillata</i>	1
Malay fishing owl.....	<i>Ketupa ketupu</i>	2
Snowy owl.....	<i>Nyctea nyctea</i>	3
Barred owl.....	<i>Strix varia</i>	16
Short-eared owl.....	<i>Asio flammeus</i>	1
Saw-whet owl.....	<i>Aegolius acadicus</i>	2

COLIIFORMES

Coliidae:

Mousebird.....	<i>Colius striatus</i>	1
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TROGONIFORMES

Trogonidae:

Cuban trogon.....	<i>Priotelus temnurus</i>	3
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CORACIIFORMES

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Alcedinidae :		
Kookaburra-----	<i>Dacelo gigas</i> -----	3
Momotidae :		
Motmot-----	<i>Momotus lesoni</i> -----	1
Coraciidae :		
Lilac-breasted roller-----	<i>Coracias caudata</i> -----	2
Indian roller-----	<i>Coracias benghalensis</i> -----	2
Bucerotidae :		
Pied hornbill-----	<i>Anthracoceros malabaricus</i> -----	1
Abyssinian ground hornbill-----	<i>Bucorvus abyssinicus</i> -----	1
Grey hornbill-----	<i>Tockus birostris</i> -----	4
Black-and-white casqued hornbill-----	<i>Bycanistes subcylindricus</i> -----	1
Great black casqued hornbill-----	<i>Ceratogymna atrata</i> -----	1

PICIFORMES

Capitonidae :		
Asiatic red-fronted barbet-----	<i>Megalaima asiatica</i> -----	1
Asiatic great barbet-----	<i>Megalaima cirrus</i> -----	1
Toucan barbet-----	<i>Semnornis ramphastinus</i> -----	1
Ramphastidae :		
White-lined toucanet-----	<i>Aulacorhynchus albivittatus</i> -----	2
Sulphur-breasted toucan-----	<i>Ramphastos carinatus</i> -----	1
Picidae :		
Golden-backed woodpecker-----	<i>Brachypternus benghalensis</i> -----	2
Scaly-bellied woodpecker-----	<i>Picus squamatus</i> -----	2

PASSERIFORMES

Cotingidae :		
Orange cock-of-the-rock-----	<i>Rupicola rupicola</i> -----	1
Pipridae :		
Long-tailed manakin-----	<i>Chiroxiphia linearis</i> -----	2
Tyrannidae :		
Kiskadee flycatcher-----	<i>Pitangus sulphuratus</i> -----	1
Pittidae :		
Indian pitta-----	<i>Pitta brachyura</i> -----	3
Alaudidae :		
Skylark-----	<i>Alauda arvensis</i> -----	1
Shore lark-----	<i>Eremophila alpestris</i> -----	2
Corvidae :		
Magpie-----	<i>Pica pica</i> -----	5
Yellow-billed magpie-----	<i>Pica nuttalli</i> -----	1
Asiatic tree pie-----	<i>Crypsirina formosae</i> -----	2
Magpie jay-----	<i>Calocitta formosa</i> -----	1
Blue jay-----	<i>Cyanocitta cristata</i> -----	1
Steller's jay-----	<i>Cyanocitta stelleri</i> -----	4
European jay-----	<i>Garrulus glandarius</i> -----	2
African white-necked crow-----	<i>Corvus albus</i> -----	2
American crow-----	<i>Corvus brachyrhynchos</i> -----	3
Raven-----	<i>Corvus corax</i> -----	2
Indian crow-----	<i>Corvus splendens</i> -----	1

Family and common name	Scientific name	Number
Corvidae—Continued		
Formosan red-billed pie.....	<i>Kitta caerulea</i>	9
Hunting crow.....	<i>Kitta chinensis</i>	1
Inca jay.....	<i>Xanthoura yncas</i>	2
Cracticidae:		
White-backed piping crow.....	<i>Gymnorhina hypoleuca</i>	1
Paridae:		
Red-headed tit.....	<i>Aegithaliscus concinnus</i>	1
Great tit.....	<i>Parus major</i>	1
Tufted titmouse.....	<i>Parus bicolor</i>	1
Chickadee.....	<i>Parus atricapillus</i>	1
Sittidae:		
Chestnut-bellied nuthatch.....	<i>Sitta castanea</i>	2
Timaliidae:		
Rusty-cheeked scimitar babbler.....	<i>Pomatorhinus erythrogenys</i>	1
Indian scimitar babbler.....	<i>Pomatorhinus horsfieldii</i>	1
Tit babbler.....	<i>Yuhina flavicollis</i>	1
Black-headed sibia.....	<i>Heterophasia capistrata</i>	2
Silver-eared mesia.....	<i>Mesia argentauris</i>	3
Pycnonotidae:		
Red-vented bulbul.....	<i>Pycnonotus cafer</i>	1
White-cheeked bulbul.....	<i>Pycnonotus leucogenys</i>	2
White-eared bulbul.....	<i>Pycnonotus leucotis</i>	1
Troglodytidae:		
Carolina wren.....	<i>Thryothorus ludovicianus</i>	1
Mimidae:		
Mockingbird.....	<i>Mimus polyglottos</i>	1
Turdidae:		
Robin, albino.....	<i>Turdus migratorius</i>	1
Cliff chat.....	<i>Thamnolaea cinnamomeiventris</i>	2
Sturnidae:		
Rose-colored pastor.....	<i>Pastor roseus</i>	1
Burchell's glossy starling.....	<i>Lamprocolius purpureus</i>	1
Long-tailed glossy starling.....	<i>Lamprotornis caudatus</i>	1
Ametbyst starling.....	<i>Spreo sp</i>	1
Tri-colored starling.....	<i>Spreo superbus</i>	1
Starling.....	<i>Sturnus vulgaris</i>	2
Jungle mynah.....	<i>Acridotheres tristis</i>	1
Lesser hill mynah.....	<i>Gracula religiosa indica</i>	1
Greater Indian hill mynah.....	<i>Gracula religiosa intermedia</i>	2
Nectariniidae:		
Violet-backed sunbird.....	<i>Anthreptes longuemare</i>	3
Scarlet-chested sunbird.....	<i>Chalcomitra rubescens</i>	1
Eastern double-collared sunbird.....	<i>Cinnyris mediocris</i>	2
Variable sunbird.....	<i>Cinnyris venustus</i>	2
Scarlet-tufted malachite sunbird.....	<i>Nectarinia johnstoni</i>	2
Beautiful sunbird.....	<i>Nectarinia pulchella</i>	1
Tecasse sunbird.....	<i>Nectarinia tacazze</i>	1
Zosteropidae:		
White-eye.....	<i>Zosterops palpebrosa</i>	3
Coerebidae:		
Blue honey-creeper.....	<i>Cyanerpes cyaneus</i>	2

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Parulidae:		
Ovenbird.....	<i>Seiurus aurocapillus</i>	1
Ploceidae:		
Red-naped widowbird.....	<i>Colius passer laticauda</i>	11
Giant whydah.....	<i>Diatropura procne</i>	2
Baya weaver.....	<i>Ploceus baya</i>	4
Vitelline masked weaver.....	<i>Ploceus vitellinus</i>	4
Mahali weaver.....	<i>Ploceipasser mahali</i>	1
Red bishop weaver.....	<i>Euplectes oriz</i>	2
Yellow-crowned bishop weaver.....	<i>Euplectes afra</i>	4
White-headed nun.....	<i>Lonchura maja</i>	6
Cut-throat weaver finch.....	<i>Amadina fasciata</i>	1
Lavender finch.....	<i>Estrilda coerulescens</i>	2
Strawberry finch.....	<i>Estrilda amandara</i>	7
Red-eared waxbill.....	<i>Estrilda astrild</i>	1
Common waxbill.....	<i>Estrilda troglodytes</i>	2
Zebra finch.....	<i>Poephila castanotis</i>	26
Gouldian finch.....	<i>Poephila gouldiae</i>	1
Java finch.....	<i>Padda oryzivora</i>	15
Icteridae:		
Rice grackle.....	<i>Psomocolax oryzivora</i>	1
Purple grackle.....	<i>Quiscalus quiscula</i>	1
Swainson's grackle.....	<i>Holoquiscalus lugubris</i>	1
Boat-tailed grackle.....	<i>Megaquiscalus major</i>	3
Shiny cowbird.....	<i>Molothrus bonariensis</i>	1
Colombian red-eyed cowbird.....	<i>Tangavius armenti</i>	1
Blackbird.....	<i>Turdus merula</i>	2
Red-breasted marshbird.....	<i>Leistes militaris</i>	4
Troupial.....	<i>Icterus icterus</i>	1
Thraupidae:		
Black-and-white tanager.....	<i>Cissopis leveriana</i>	1
Yellow-rumped tanager.....	<i>Ramphocelus icteronotus</i>	2
Passerini's tanager.....	<i>Ramphocelus passerinii</i>	1
Red tanager.....	<i>Pyranga rubra</i>	1
Fringillidae:		
Rice grosbeak.....	<i>Oryzoborus crassirostris</i>	1
Evening grosbeak.....	<i>Hesperiphona vespertina</i>	6
Brazilian cardinal.....	<i>Paroaria cucullata</i>	1
Black-throated cardinal.....	<i>Paroaria gularis</i>	1
Cardinal.....	<i>Richmondia cardinalis</i>	12
European goldfinch.....	<i>Carduelis caniceps</i>	3
European goldfinch X canary, hybrid.....	<i>Carduelis carduelis</i> X <i>Serinus canarius</i>	1
Canary.....	<i>Serinus canarius</i>	5
Green finch.....	<i>Chloris chloris</i>	2
Lesser yellow finch.....	<i>Sicalis lutcola</i>	2
European bullfinch.....	<i>Pyrrhula rubicilla</i>	4
Melodious grassquit.....	<i>Tiaris canora</i>	1
Chaffinch.....	<i>Fringilla coelebs</i>	2
Slate-colored junco.....	<i>Junco hyemalis</i>	5
Buff-throated saltator.....	<i>Saltator maximus</i>	2
Tawny-bellied seedeater.....	<i>Sporophila minuta</i>	4

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Fringillidae—Continued		
Song sparrow.....	<i>Melospiza melodia</i>	1
Dickcissel.....	<i>Spiza americana</i>	8
White-throated sparrow.....	<i>Zonotrichia albicollis</i>	6
White-crowned sparrow.....	<i>Zonotrichia leucophrys</i>	2

REPTILES

LORICATA

Alligatoridae:		
Caiman.....	<i>Caiman sclerops</i>	1
American alligator.....	<i>Alligator mississippiensis</i>	10
Chinese alligator.....	<i>Alligator sinensis</i>	2
Crocodylidae:		
Broad-nosed crocodile.....	<i>Osteolaemus tetraspis</i>	2
African crocodile.....	<i>Crocodylus niloticus</i>	2
Narrow-nosed crocodile.....	<i>Crocodylus cataphractus</i>	1
Salt-water crocodile.....	<i>Crocodylus porosus</i>	1
American crocodile.....	<i>Crocodylus acutus</i>	2
Gavialidae:		
Indian gavial.....	<i>Gavialis gangeticus</i>	1

CHELONIA

Chelydridae:		
Snapping turtle.....	<i>Chelydra serpentina</i>	Many
Alligator snapping turtle.....	<i>Macrochelys temminckii</i>	4
Kinosternidae:		
Musk turtle.....	<i>Sternotherus odoratus</i>	3
Mud turtle.....	<i>Kinosternon subrubrum</i>	7
South American mud turtle.....	<i>Kinosternon cruentatum</i>	2
Emydidae:		
Box turtle.....	<i>Terrapene carolina</i>	Many
Three-toed box turtle.....	<i>Terrapene c. triunguis</i>	3
Western box turtle.....	<i>Terrapene ornata</i>	1
Florida box turtle.....	<i>Terrapene bauri</i>	1
Kura box turtle.....	<i>Curora amboinensis</i>	2
Diamondback turtle.....	<i>Malaclemys terrapin</i>	5
Map turtle.....	<i>Graptemys geographica</i>	2
False map turtle.....	<i>Graptemys pseudogeographica</i>	2
Barbour's turtle.....	<i>Graptemys barbouri</i>	5
Painted turtle.....	<i>Chrysemys picta</i>	Many
Cumberland turtle.....	<i>Pseudemys scripta troostii</i>	23
South American red-lined turtle.....	<i>Pseudemys scripta callirostris</i>	6
Yellow-bellied turtle.....	<i>Pseudemys scripta scripta</i>	15
Red-bellied turtle.....	<i>Pseudemys rubriventris</i>	8
Mobile turtle.....	<i>Pseudemys elegans</i>	12
Florida water turtle.....	<i>Pseudemys floridana</i>	17
Central American turtle.....	<i>Pseudemys ornata</i>	2
Cuban water turtle.....	<i>Pseudemys decussata</i>	1
Chicken turtle.....	<i>Deirochelys reticularia</i>	2
Spotted turtle.....	<i>Clemmys guttata</i>	2
Wood turtle.....	<i>Clemmys insculpta</i>	6
Pacific pond turtle.....	<i>Clemmys marmorata marmorata</i>	1
North African pond turtle.....	<i>Clemmys leprosa</i>	2

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Emydidae—Continued		
European pond turtle.....	<i>Emys orbicularis</i>	3
Blanding's turtle.....	<i>Emys blandingii</i>	3
Indian fresh-water turtle.....	<i>Batagur baska</i>	1
Reeves's turtle.....	<i>Geoclemys reevesii</i>	4
Testudinidae:		
Giant Aldabra tortoise.....	<i>Testudo elephantina</i>	2
Galapagos tortoise.....	<i>Testudo clephantopus</i>	1
Galapagos tortoise.....	<i>Testudo vicina</i>	2
Duncan Island tortoise.....	<i>Testudo ephippium</i>	2
South American tortoise.....	<i>Testudo tabulata</i>	1
Desert tortoise.....	<i>Testudo agassizii</i>	2
European tortoise.....	<i>Testudo graeca</i>	1
Radiated tortoise.....	<i>Testudo radiata</i>	1
Pelomedusidae:		
African water turtle.....	<i>Pelomedusa subrufa</i>	2
African black mud turtle.....	<i>Pelusios nigricans</i>	1
Amazon spotted turtle.....	<i>Podocnemis unifilis</i>	10
Chelydidae:		
South American side-necked turtle.....	<i>Batrachemys nasuta</i>	2
Australian side-necked turtle.....	<i>Chelodina longicollis</i>	3
Small side-necked turtle.....	<i>Hydromedusa tectifera</i>	2
Large side-necked turtle.....	<i>Phrynosoma hilarii</i>	11
Kreff's turtle.....	<i>Emydura krefftii</i>	3
Murray turtle.....	<i>Emydura macquarrii</i>	6
South American gibba turtle.....	<i>Mesoclemmys gibba</i>	3
Flat-headed turtle.....	<i>Platemys platycephala</i>	7
Trionychidae:		
Florida soft-shelled turtle.....	<i>Trionyx ferox</i>	6
African soft-shelled turtle.....	<i>Trionyx triunguis</i>	2

SAURIA

Gekkonidae:		
Gecko.....	<i>Tarentola mauritanica</i>	1
Giant gecko.....	<i>Gekko stenotor</i>	1
Nelson's gecko.....	<i>Aristelliger nelsoni</i>	1
Indian gecko.....	<i>Gekko</i> sp.....	1
Iguanidae:		
Common Iguana.....	<i>Iguana iguana</i>	3
Swan Island iguana.....	<i>Iguana delicatissima</i>	4
Carolina anole.....	<i>Anolis carolinensis</i>	Many
Nelson's anolis.....	<i>Anolis nelsoni</i>	2
Giant anole.....	<i>Anolis equestris</i>	1
Texas horned lizard.....	<i>Phrynosoma cornutum</i>	1
Horned lizard.....	<i>Phrynosoma platyrhinos</i>	1
Crested lizard.....	<i>Leiocephalus varius</i>	3
Blue scaly lizard.....	<i>Sceloporus cyanogenys</i>	1
Red scaly lizard.....	<i>Sceloporus poinsettii</i>	2
Fence lizard.....	<i>Sceloporus undulatus</i>	1
Ameiva lizard.....	<i>Ameiva a. ameiva</i>	1
British Guiana green lizard.....	<i>Centropyx striatus</i>	1
Black iguana.....	<i>Ctenosaura acanthura</i>	1
Desert iguana.....	<i>Dipsosaurus dorsalis</i>	3

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Scincidae:		
Mourning skink-----	<i>Egernia luctuosa</i> -----	2
White's skink-----	<i>Egernia whitei</i> -----	4
Greater five-lined skink-----	<i>Eumeces fasciatus</i> -----	7
Sand skink-----	<i>Scincus officinalis</i> -----	5
Stump-tailed skink-----	<i>Tiliqua rugosa</i> -----	1
Malayan skink-----	<i>Mabuya multifasciata</i> -----	3
Gerrhosauridae:		
Plated lizard-----	<i>Gerrhosaurus major</i> -----	2
Teiidae:		
Black tegu-----	<i>Tupinambis nigropunctatus</i> -----	1
Yellow tegu-----	<i>Tupinambis teguixin</i> -----	1
Whiptail lizard-----	<i>Cnemidophorus gularis</i> -----	1
Varanidae:		
Duméril's monitor lizard-----	<i>Varanus dumerili</i> -----	1
Indian monitor lizard-----	<i>Varanus flavescens</i> -----	6
Indian monitor lizard-----	<i>Varanus salvator</i> -----	1
Australian lace monitor-----	<i>Varanus varius</i> -----	3
Clouded monitor-----	<i>Varanus nebulosus</i> -----	1
Helodermatidae:		
Mexican beaded lizard-----	<i>Heloderma horridum</i> -----	2
Beaded lizard (black phase)-----	<i>Heloderma horridum</i> -----	1
Gila monster-----	<i>Heloderma suspectum</i> -----	2
Anguidae:		
Glass lizard-----	<i>Ophisaurus ventralis</i> -----	3

SERPENTES

Boidae:		
Anaconda-----	<i>Eunectes murinus</i> -----	3
Tree boa-----	<i>Boa enydri enydri</i> -----	1
Cook's tree boa-----	<i>Boa enydri cooki</i> -----	11
Boa constrictor-----	<i>Constrictor constrictor</i> -----	1
Emperor boa-----	<i>Constrictor imperator</i> -----	1
Rubber boa-----	<i>Charina bottae</i> -----	2
Cuban ground boa-----	<i>Tropidophis melanura</i> -----	1
Rainbow boa-----	<i>Epicrates cenchria</i> -----	2
Cuban tree boa-----	<i>Epicrates angulifer</i> -----	5
Ball python-----	<i>Python regius</i> -----	1
African python-----	<i>Python sebae</i> -----	1
Indian rock python-----	<i>Python molurus</i> -----	4
Regal python-----	<i>Python reticulatus</i> -----	1
Colubridae:		
Water snake-----	<i>Natrix sipedon</i> -----	1
European grass snake-----	<i>Natrix natrix</i> -----	1
Southern banded water snake-----	<i>Natrix fasciata</i> -----	2
Diamond-backed water snake-----	<i>Natrix rhombifera</i> -----	1
Brown water snake-----	<i>Natrix taxispilota</i> -----	4
Red-bellied water snake-----	<i>Natrix erythrogaster</i> -----	2
Island water snake-----	<i>Natrix insularum</i> -----	1
Mangrove snake-----	<i>Natrix compressicauda</i> -----	1
Garter snake-----	<i>Thamnophis sirtalis sirtalis</i> -----	3
California red-sided garter snake-----	<i>Thamnophis sirtalis infernalis</i> -----	1

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Colubridae—Continued		
Eastern hog-nosed snake.....	<i>Heterodon platyrhinos</i>	1
Ring-necked snake.....	<i>Diadophis punctatus edwardsii</i>	1
Black racer.....	<i>Coluber constrictor constrictor</i>	4
Red racer.....	<i>Masticophis flagellum</i>	1
Green snake.....	<i>Ophedrys aestivus</i>	1
Indigo snake.....	<i>Drymarchon corais couperi</i>	1
Texas indigo snake.....	<i>Drymarchon corais</i>	1
Asiatic rat snake.....	<i>Elaphe taeniura</i>	2
Lesser Indian rat snake.....	<i>Elaphe carinata</i>	2
Pilot black snake.....	<i>Elaphe obsoleta obsoleta</i>	7
Fox snake.....	<i>Elaphe vulpina</i>	1
Corn snake.....	<i>Elaphe obsoleta guttata</i>	3
Lindheimer's rat snake.....	<i>Elaphe obsoleta lindheimeri</i>	1
Chicken snake.....	<i>Elaphe quadrivittata</i>	1
Aesculapian snake.....	<i>Elaphe longissima</i>	1
Bull snake.....	<i>Pituophis sayi</i>	2
King snake.....	<i>Lampropeltis getulus getulus</i>	3
Speckled king snake.....	<i>Lampropeltis getulus holbrooki</i>	3
California king snake.....	<i>Lampropeltis getulus californiae</i>	2
Sonoran king snake.....	<i>Lampropeltis getulus splendida</i>	1
Scarlet king snake.....	<i>Lampropeltis dolia dolia</i>	2
Milk snake.....	<i>Lampropeltis triangulum</i>	2
Tropical king snake.....	<i>Lampropeltis polyzonus</i>	1
Cat-eyed snake.....	<i>Leptodeira annulata</i>	1
DeKay's snake.....	<i>Storeria dekayi</i>	1
Flying snake.....	<i>Chrysopetala ornata</i>	1
Twig, or vine, snake.....	<i>Thelotornis kirtlandi</i>	1
Green whip snake.....	<i>Dryophis prasinus</i>	1
File snake.....	<i>Simocephalus capensis</i>	1
Glossy snake.....	<i>Arizona elegans</i>	1
European whip snake.....	<i>Zamenis gemonensis</i>	1
Wolf snake.....	<i>Lycodon flavomaculatus</i>	4
Elapidae:		
Indian cobra.....	<i>Naja naja</i>	4
Taiwan cobra.....	<i>Naja naja atra</i>	17
Egyptian cobra.....	<i>Naja haje</i>	1
Krait.....	<i>Bungarus multicinctus</i>	1
Acrochordidae:		
Elephant trunk snake.....	<i>Acrochordus javanicus</i>	1
Crotalidae:		
Southern copperhead.....	<i>Ancistrodon contortrix contortrix</i>	1
Northern copperhead.....	<i>Ancistrodon contortrix mokeson</i>	4
Western broad-banded copperhead.....	<i>Ancistrodon contortrix laticinctus</i>	1
Water moccasin, or cottonmouth.....	<i>Ancistrodon piscivorus</i>	5
Cantil.....	<i>Ancistrodon bilineatus</i>	1
Mamushi.....	<i>Ancistrodon halys blomhoffi</i>	2
Asian snorkel viper.....	<i>Ancistrodon acutus</i>	3
Green palm viper.....	<i>Trimercsurus gramineus</i>	2
Green palm viper.....	<i>Trimercsurus stejnegeri</i>	3

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Crotalidae—Continued		
Wagler's pit viper.....	<i>Trimeresurus wagleri</i>	1
Mamushi, or Asiatic viper.....	<i>Trimeresurus elegans</i>	2
Habu, or Asiatic viper.....	<i>Trimeresurus flavoviridis</i>	1
Timber rattlesnake.....	<i>Crotalus horridus</i>	1
Southern Pacific rattlesnake.....	<i>Crotalus viridis helleri</i>	6
Prairie rattlesnake.....	<i>Crotalus viridis viridis</i>	1
Western diamondback rattlesnake....	<i>Crotalus atrox</i>	6

AMPHIBIANS

CAUDATA

Amphiumidae:		
Congo eel.....	<i>Amphiuma means</i>	3
Ambystomidae:		
Tiger salamander.....	<i>Ambystoma tigrinum</i>	1
Salamandridae:		
Red-bellied newt.....	<i>Dicmictylus pyrrhogaster</i>	10
Red-spotted newt.....	<i>Dicmictylus viridescens</i>	25

SALIENTIA

Bufonidae:		
American toad.....	<i>Bufo americanus</i>	2
Giant toad.....	<i>Bufo marinus</i>	5
Cuban toad.....	<i>Bufo peltoccephalus</i>	6
Pelobatidae:		
Spadefoot toad.....	<i>Scaphiopus holbrooki</i>	5
Pipidae:		
Surinam toad.....	<i>Pipa pipa</i>	20
Leptodactylidae:		
Colombian horned frog.....	<i>Ceratophrys calcarata</i>	2
Argentine horned frog.....	<i>Ceratophrys ornata</i>	1
Hylidae:		
Barking tree frog.....	<i>Hyla gratiosa</i>	1
Green tree frog.....	<i>Hyla cinerea</i>	1
Gray tree frog.....	<i>Hyla versicolor</i>	4
Microhylidae:		
Narrow-mouthed toad.....	<i>Microhyla olivacea</i>	1
Ranidae:		
African bull frog.....	<i>Rana adspersa</i>	7
American bull frog.....	<i>Rana catesbeiana</i>	3
Green frog.....	<i>Rana clamitans</i>	5
Leopard frog.....	<i>Rana pipiens</i>	Many

ARTHROPODS

DECAPODA

Cenobitidae:		
Land hermit crab.....	<i>Coenobita clypeatus</i>	Many

ARANEIDA

Theridiidae:		
Black-widow spider.....	<i>Latrodectus mactans</i>	1

ORTHOPTERA

<i>Family and common name</i>	<i>Scientific name</i>	<i>Number</i>
Blattidae:		
Tropical giant cockroach-----	<i>Blaberus giganteus</i> -----	Many

MOLLUSKS

PULMONATA

Planorbidae:		
Pond snail-----	<i>Helisoma trivolvis</i> -----	Many

FISHES

NEOCERATODONTOIDEI

Lepidosirenidae:		
South American lungfish-----	<i>Lepidosiren paradoxa</i> -----	1
Protopteridae:		
African lungfish-----	<i>Protopterus annectens</i> -----	2

OSTARIOPHYSOIDEI

Characidae:		
Metynnis-----	<i>Metynnis roosevelti</i> -----	1
Black tetra-----	<i>Gymnocorymbus ternetzi</i> -----	3
Gymnotidae:		
African knifefish-----	<i>Sternarchella schotti</i> -----	1
Cyprinidae:		
Zebra fish-----	<i>Brachydanio rerio</i> -----	9
Clown barb-----	<i>Barbus everetti</i> -----	1
Tiger barb-----	<i>Puntius partipentazona</i> -----	8
White Cloud Mountain fish-----	<i>Tanichthys albonubes</i> -----	15

CYPRINODONTOIDEI

Poeciliidae:		
Flag-tailed guppy-----	<i>Lebistes reticulatus</i> -----	10
Guppy-----	<i>Lebistes reticulatus</i> -----	15
Black mollie-----	<i>Mollienisia latipinna</i> -----	2
Platy, or moonfish-----	<i>Xiphophorus maculatus</i> -----	1

PERCOMORPHOIDEI

Anabantoldea:		
Climbing perch-----	<i>Anabas testudineus</i> -----	3
Cichlidae:		
Peacock cichlid-----	<i>Astronotus ocellatus</i> -----	1
Egyptian mouthbreeder-----	<i>Haplochromis multicolor</i> -----	3
Angelfish-----	<i>Pterophyllum eimekei</i> -----	2
"Jack Dempsey" fish-----	<i>Cichlasoma biocellatum</i> -----	35
Jewel fish-----	<i>Hemichromis bimaculatus</i> -----	1

FINANCES

Funds for the operation of the National Zoological Park are appropriated annually under the District of Columbia Appropriation Act. The operation and maintenance appropriation for the fiscal year 1960 totaled \$1,165,200, which was \$211,400 more than for the fiscal year

1959. The increase consisted of \$41,200 to cover wage-board salary increases; \$19,100 for within-grade salary advancements for both classified and wage-board employees; \$130,600 to establish 28 new positions; \$9,000 increase for the purchase of animal food; \$2,500 in miscellaneous supplies; and \$9,000 for the purchase of new equipment.

Of the total appropriation, 82.3 percent (\$958,631) was used for salaries and related personnel costs and 17.7 percent (\$206,569) for the maintenance and operation of the Zoo. Included in the latter figure were \$74,000 for animal food; \$17,296 for fuel for heating; \$32,598 for materials for building construction and repairs; \$8,090 for the purchase of animals; \$9,600 for electricity; \$4,871 for telephone, postal, and telegraph services; and \$5,000 for veterinarian equipment and supplies. The balance of \$55,114 in operational funds was expended for other items, including freight, sundry supplies, uniforms, gasoline, road repairs, equipment replacement, and new equipment.

In addition to the regular appropriation \$130,000 was appropriated for capital outlay: \$44,000 to repair the roofs of the small mammal house, large mammal house, and reptile house; and \$86,000 for safety improvements.

PERSONNEL

In fiscal year 1960 there were 186 authorized positions at the Zoo divided as follows: Administrative office, 16; animal department, 70, an increase of 12 over the previous year; mechanical department, 61, an increase of 11; police department, 30, an increase of 3; and grounds department, 9, an increase of 2.

Lt. J. R. Wolfe was appointed chairman of the safety committee, succeeding Dr. James F. Wright, who will continue as a member of the subcommittee. Lt. C. E. Brink replaced Lt. Wolfe as the police department member of the subcommittee.

Capt. William R. James recruited and organized a group of 15 Zoo employees to receive training at the Civil Defense Fire School. First-aid classes were organized with Pvt. C. S. Grubbs of the police department and L. Ratliff of the animal department as instructors.

Ernest Cook, supervisory animal keeper, retired on March 9, 1960, after serving the Zoo since December 1, 1930. During most of those years he worked in the bird house.

FRIENDS OF THE NATIONAL ZOO

"Friends of the National Zoo," a group of civic-minded District residents, were active again this year. On September 26 and 27 they carried out a two-day "Salute to the National Zoo," which drew 53,000 visitors. Embassies and State societies donated flags which were flown

in front of many of the cages, indicating the country of origin of the animal on exhibit. Special labels set in laminated plastic were written for 16 exhibits. On the second day of the "Salute" a new flagpole was formally dedicated "in warm admiration for Dr. William M. Mann, former Director." Max Kampelman, president of the Friends of the National Zoo, made the presentation, which was accepted by Dr. Remington Kellogg, representing the Smithsonian Institution. Zoo Park Police Officers Trautman, Ellerbe, and Moore formed a mounted color guard as the new 49-star flag was raised to the top of the flagpole at the Connecticut Avenue entrance to the Zoo.

On December 14 at the Chancery of the Israeli Embassy in Washington the National Zoological Park received a set of 50 plaques designed as labels for zoo animals mentioned in the Old Testament. These are replicas of the labels used in the Biblical Zoo in Jerusalem and have, besides the name of the animal, the appropriate text quoted in both English and Hebrew. The plaques themselves are of laminated plastic in soft shades of blue, green, and bronze, with the lettering in white. They have been installed in the Zoo and will later be sent as a traveling exhibit to other interested zoos in the States, returning to Washington as a permanent exhibit. At the ceremony at the Chancery, the plaques were presented to the Director of the National Zoological Park by Machael Arnon, Counselor of the Embassy. Among those present were Dr. John L. Keddy, representing the Smithsonian Institution, John Perry, president of the Friends of the National Zoo, J. Lear Grimmer, Associate Director of the Zoo, and Dr. William M. Mann, former Director.

INFORMATION AND EDUCATION

The Zoo continues to handle a large correspondence with persons all over the world who write for information regarding animals. From every part of this country citizens write to the Zoo as a national institution. Telephone calls come in constantly, asking for identification of animals, proper diets, or treatment of disease. Visitors to the office as well as to the animal exhibits are constantly seeking information.

The Director spent seven weeks (August to October) in Europe, attending the meeting of the International Union of Directors of Zoological Gardens in Copenhagen, Denmark, and visiting zoological parks in Russia, Germany, Switzerland, Holland, Belgium, France, and the British Isles. Particular studies were made of new construction and methods of management. On his return he lectured before various civic and scientific groups and showed his pictures of the European zoos. He also gave one radio interview.

Dr. James F. Wright, veterinarian, went to Senegal, West Africa, at the request of the Forestry Department of that country to instruct its officers in the use of the "flying syringe." The Senegalese Government was interested in this method of immobilizing animals because of the necessity of relocating some of the herds of game, which they wished to do with as little loss of individual animals as possible. While in Senegal, Dr. Wright captured a defassa kob, which was sent to the Zoo in Brazzaville, Congo. As far as is known, this is the first example of a wild animal being captured by the projectile syringe for exhibition in a zoo.

Dr. Wright participated in a "Symposium on the Automatic Projectile Syringe" at the University of Georgia, Athens, Ga., in April 1960. He spoke on "The Projectile Delivery of Drugs in Zoo Work" and (with Dr. Warren R. Pistey of the University of Virginia) on "Immobilization of Captive Wild Animals with Succinylcholine."

Malcolm Davis, associate headkeeper, spoke to civic and church groups, and also to the Northern Virginia Ornithological Society. He continued to write a weekly nature column for the *Herndon-Chantilly Times* and to edit the publication "Capsules" for the Woodard Research Corporation in Herndon, Va.

Keepers Burgess, DePrato, Maliniak, and Widman brought Zoo animals to the television screen repeatedly. Many of these programs were broadcast on the "Time for Science" series from station WTTG, sponsored by the Greater Washington Educational Television Association, and watched by 50,000 students in the District of Columbia, Maryland, and Virginia. The same program also made a film in the Zoo of mammals, birds, and reptiles, which was shown over WTTG.

Ordinarily the Zoo does not conduct guided tours of the Park, but exceptions were made for groups of handicapped children—orthopedic cases, a small group of blind children from Hyattsville (Md.) Elementary School, and 30 deaf children from Gallaudet College. The largest of these groups consisted of 60 handicapped children who were brought to the Zoo by the Kiwanis Club. In all cases police and keepers escorted them.

The Department of Zoology, University of Maryland, brought a class of 12 students of vertebrate zoology to study the living animals. This course, which was under the direction of Dr. Howard Winn, included four visits to the Zoo, and studies were made of mammals, birds, and reptiles. Tape recordings of sounds of small mammals and of bird songs were made, to be played back later in the classroom.

The Virginia Herpetology Society met in the reptile house on November 14, 1959, and members were given a guided tour by Senior Keeper Mario DePrato. Mr. DePrato also spoke to a class of students from Taylor School who visited the reptile house.

A group of 1,620 foreign exchange students visited the Park on July 16, 1959; and 16,785 School Safety Patrol children, in 420 buses, came to the Zoo on May 14, 1960, from many parts of the United States.

While the Zoo does not conduct a regular research program as such, effort is made to study the animals and to improve their health, housing, and diet in every way possible.

REPORT OF THE VETERINARIAN

As reported in previous years (1958, 1959) the projectile type of syringe proved its usefulness in providing medication for captive animals. With this method it is not necessary to rope, manhandle, trap, or cage animals or exhaust either animals or keepers. As the operator seldom needs help in using it, a considerable saving in man-hours is also effected.

With the use of the projectile syringe and the immobilizing techniques, three interesting surgical operations were performed. One was the removal of a large goiter from a male spotted hyena anesthetized with a new barbiturate. A survey of the available records indicates that this type of thyroid enlargement has been found in the past in hyenas in the National Zoological Park. The animal had been treated medically for six months prior to surgery without noticeable improvement. A small fibroma was removed from the back of an Alaskan brown bear, using pentobarbital sodium intravenously as an anesthetic and succinylcholine chloride intramuscularly as a pre-anesthetic. The pre-anesthetic facilitated a smooth and quick induction of the intravenous barbiturate. A broken tooth was removed from one of the female Malay sun bears with succinylcholine chloride and a local anesthetic. With the newer techniques, this operation was completed in a few minutes instead of the more usual several hours.

A preliminary report on the use of succinylcholine chloride was published in *Veterinary Medicine* (vol. 54, p. 446, Sept. 1959), and a more complete paper was presented by Dr. Warren R. Pistey at a symposium on the automatic projectile syringe at the University of Georgia in April 1960.

To the animals listed in last year's report as successfully immobilized with this drug, the following can be added: Alaskan brown bear, spectacled bear, Peninsula bear, hybrid bear, Formosan macaque, rhesus monkey, European brown bear, sloth bear, and Malayan sun bear.

Work with alkaloidal nicotine as an immobilizing agent was continued on native white-tailed deer in cooperation with Dr. Vagn Flyger of the State of Maryland Department of Research and Education.

Capchurbarb was used for the first time on captive wild animals this past spring with excellent results. Depending on the dosage, this drug may be used for immobilization, sedation, or for anesthesia by the intramuscular route. The following species were successfully immobilized with this drug: peccary, tahr goat, white fallow deer, Formosan macaque, spotted hyena, and Nubian ibex. Results so far indicate that this drug will have a far greater application than any of the others for immobilization.

During April 1960, Maj. Patrick Bromfield, game control officer of the Bechuanaland Protectorate, spent some time in the National Zoological Park studying the use of the automatic projectile syringe and methods of immobilization, in order to translocate game in the Protectorate. He also conferred with game officials in Maryland, Georgia, Tennessee, and the National Park Service.

Tuberculosis remains the most important health problem in our hoofed animals. In the recent past, animals that have not reacted to the intradermic tuberculin test were found infected with tuberculosis at necropsy. This loss of sensitivity to tuberculin is apparently not uncommon in the later stages of the disease. Arrangements were made with the U.S. Department of Agriculture to determine the presence of serum antibodies for tuberculosis in suspect animals. Accordingly, two elands and a giraffe, all suspect but not reacting to the intradermic test, were immobilized with succinylcholine and blood samples were obtained for serology.

A hybrid Philippine and Javan macaque with severe central nervous system symptoms showed, upon pathological examination, to have had cerebral and pulmonary forms of cryptococcosis. Seven other monkeys of various species were sent to the Armed Forces Institute of Pathology since last year, all of which, during life, had shown signs of acute amaurotic epilepsy as described by Langdon and Cadwallader in 1915 and Van Bogaert and Scherer in 1935. Some of these monkeys were sent for euthanasia in the last stages of the disease. Keepers in the monkey house state that this condition has occurred there for years without an apparent change in morbidity or severity. The pathologists' report is not completed at this time, but it is felt that the disease is not contagious, if indeed infectious.

Dr. F. R. Lucas, Livestock Sanitary Laboratory, Centreville, Md., provided the following laboratory services: bacterial cultures and identification, urinalysis, dark field examinations for *Leptospira*, and microscopic tissue reports.

Hearts and large vessels of necropsy specimens not needed by the Armed Forces Institute of Pathology were delivered to Dr. Thomas Peery of the George Washington University School of Medicine for his study of comparative pathology.

Parasitological identifications were conducted by Mrs. Mabelle Chitwood and Allen McIntosh of the U.S. Department of Agriculture's Animal Disease and Parasite Research Division. A. P. Cannon of the University of Kansas, currently at the University of Maryland, made blood smears from 55 snakes revealing 12 individuals of 8 species harboring hemogregarine blood parasites. The subject of these blood parasites in snakes would support a full-time research project for investigation.

A cooperative investigation was originated with Dr. William L. Straus, W. J. Young, and T. Merz, of Johns Hopkins University to study chromosomes in primates by obtaining blood samples from the available subjects. Mr. Young is also interested in studying the genetic structure of the hybrid bears, F^1 and F^2 , by working with blood samples which can now be easily obtained by immobilizing the animals.

Several alligators, both small and medium sized, were provided to Dr. A. G. Morrow and Dr. L. J. Greenfield of the National Heart Institute, for anatomical and physiological studies on the cardiac system, since these reptiles have normal hearts which are similar in construction to the hearts of children with congenital heart defects.

Two Indian pythons and two American alligators were taken to the Department of Biophysics at Walter Reed Army Medical Center to assist Maj. K. T. Woodward in determining the muscle mass of various animals by the use of a scintillating counter which measures muscle potassium.

Following are the statistics for the mortality rates during the past fiscal year and a table of comparison with the past six fiscal years:

Mortality, fiscal year 1960			Total mortality, past 6 fiscal years	
	Death	Attrition*		
Mammals.....	114	39	1955.....	735
Birds.....	140	35	1956.....	618
Reptiles.....	112	92	1957.....	549
			1958.....	550
			1959.....	472
			1960.....	532
	366	166		

*Attrition is the term used for those losses due mainly to the trauma of shipment and handling after accession at the Zoo, or before an animal can adapt to cage habitation within the collection.

Animals that had been in the collection for a relatively long time and died this year were: A Swinhoe's pheasant (*Gennaesus swinhoii*) received August 11, 1931, died August 10, 1959, after 28 years; an Indian crow (*Corvus insolens*), received September 28, 1937, from the National Geographic Society-Smithsonian Institution Expedition to the Netherlands East Indies, died November 4, 1959, after 22 years

1 month 7 days; a short-tailed shrew (*Blarina brevicauda*), which usually does not live in captivity, was exhibited from December 27, 1957, to March 28, 1960, a total of 2 years 3 months 1 day; and a marabou stork (*Leptopilus crumeniferus*), received from the Victor J. Evans estate on February 20, 1931, died May 19, 1960, after 29 years 3 months.

COOPERATION

At all times special efforts are made to maintain friendly contacts with other Federal and State agencies, private concerns and individuals, and scientific workers for mutual assistance. As a result, the Zoo receives much help and advice and many valuable animals, and in turn it furnishes information and, whenever possible, animals it does not need.

Special acknowledgment is due George Kirk and John Pulaski, in the office of the U.S. Dispatch Agent in New York City, and Stephen E. Lato, dispatch agent in San Francisco, who are frequently called upon to clear shipments of animals coming from abroad, often at great personal inconvenience. The animals have been forwarded to Washington without the loss of a single individual.

When it is necessary to quarantine animals coming into this country, they are taken to the U.S. Department of Agriculture's station in Clifton, N.J. During the past year Dr. B. C. Swindell and Andy Goodel, two of the officials stationed there, have been most cooperative in keeping the National Zoological Park informed as to the well-being of animals and birds held there for quarantine.

Animals that die in the Zoo are offered to the United States National Museum. If the Museum does not need them, they may be sent to research workers in other institutions. During the past year the Museum accepted 41 mammals, which are to be preserved as scientific specimens.

The Zoo cooperated with the National Capital Parks and lent small animals to Park naturalists and to the Nature Center in Rock Creek Park for demonstration. A collection of reptiles was loaned to Walter Reed Army Medical Center in order to have a film made of poisonous snakes. Senior Keeper W. Widman trapped a number of sea gulls for a research project at the National Institutes of Health.

Gifts of plants were received from Mount Vernon, the Botanical Gardens, St. Elizabeths Hospital, the Naval Observatory, and the Soldiers' Home.

VISITORS

Attendance at the Zoo this year reached a total of 4,059,804. In general, this figure is based on estimates rather than actual counts.

Estimated number of visitors for fiscal year 1960

July (1959).....	516, 829	January (1960).....	127, 900
August.....	446, 000	February.....	86, 150
September.....	364, 500	March.....	216, 425
October.....	302, 300	April.....	515, 400
November.....	180, 400	May.....	632, 200
December.....	93, 600	June.....	578, 100
		Total.....	4, 059, 804

Number of bus groups

Locality	Number of groups	Number in groups	Locality	Number of groups	Number in groups
Alabama.....	16	546	Nebraska.....	1	40
Connecticut.....	23	950	New Hampshire.....	4	130
District of Columbia.....	131	5, 714	New Jersey.....	23	1, 166
Delaware.....	7	320	New York.....	154	6, 054
Florida.....	28	2, 911	North Carolina.....	204	8, 943
Georgia.....	31	6, 623	Ohio.....	35	2, 031
Illinois.....	3	130	Oklahoma.....	1	60
Indiana.....	5	224	Pennsylvania.....	211	13, 177
Iowa.....	1	48	South Carolina.....	51	2, 164
Kentucky.....	14	578	South Dakota.....	1	31
Massachusetts.....	6	318	Tennessee.....	70	3, 040
Maine.....	1	33	Texas.....	1	60
Maryland.....	554	2, 222	West Virginia.....	35	1, 667
Michigan.....	5	174	Wisconsin.....	3	228
Minnesota.....	9	357	Virginia.....	413	29, 436
Mississippi.....	4	116	Total.....	2, 045	89, 491

Groups from foreign countries

	Number of groups	Number in groups		Number of groups	Number in groups
Asia.....	2	110	Korea.....	2	105
Ecuador.....	1	7	Norway.....	5	161
Foreign officers.....	2	91	Sweden.....	1	28
International exchange students.....	1	1, 620	Thailand.....	1	35
Japan.....	1	15	Total.....	16	2, 172

About 2 p.m. each day the cars then parked in the Zoo are counted and listed according to the State, Territory, or country from which they come. This is, of course, not a census of the cars coming to the Zoo but is valuable in showing the percentage of attendance by States of people in private automobiles. Many District of Columbia, Maryland, and Virginia cars come to the Zoo to bring guests from other States. The tabulation for the fiscal year 1960 is as follows:

	<i>Percentage</i>		<i>Percentage</i>
Maryland.....	32.3	California.....	0.7
Virginia.....	23.0	Connecticut.....	.7
District of Columbia.....	20.5	Michigan.....	.7
Pennsylvania.....	3.5	South Carolina.....	.6
New York.....	2.5	Illinois.....	.6
North Carolina.....	2.0	Tennessee.....	.6
New Jersey.....	1.6	Texas.....	.4
Ohio.....	1.5	Georgia.....	.4
West Virginia.....	1.1	Indiana.....	.4
Florida.....	1.1		
Massachusetts.....	.9	Total.....	95.1

The remaining 4.9 percent came from other States, Arabia, Azores, British Columbia, Canal Zone, Cuba, England, France, Guatemala, Germany, Japan, Manitoba, Mexico, Morocco, New Brunswick, Newfoundland, Nova Scotia, Okinawa, Panama, Puerto Rico, Virgin Islands, and Yugoslavia.

On the days of even small attendance there are cars parked in the Zoo from at least 15 States, Territories, the District of Columbia, and foreign countries. On average days there are cars from about 22 States, Territories, the District of Columbia, and foreign countries; and during the periods of greatest attendance the cars represent not less than 34 different States, Territories, and countries.

Parking spaces in the Zoo now accommodate 1,079 cars when the bus parking place is utilized and 969 cars when it is not used.

At the request of the Board of Regents of the Smithsonian Institution and the Commissioners of the District of Columbia, a survey was made during the year to determine the residence of the visitors by percentage. The work was done by the Zoo police under the guidance of Albert Mindlin and Samuel Rosenthal, analytical statisticians of the Management Office of the District of Columbia.

Three categories of residence were listed: District of Columbia, suburbs (the surrounding four counties), and the rest of the country. Mr. Mindlin set up a method of sampling that was scientifically designed and conducted to produce statistically valid and reliable results. To accomplish this a random sampling of all visitors in the Zoo was to be taken from one spot in the Zoo. Following pre-test surveys made in several spots scattered throughout the Zoo at various times of the day, the spot finally selected was at the water fountain

between the bears and the hardy cats. To insure that the police officers doing the interviewing were completely unable to affect, either intentionally or unintentionally, the random sampling of the visitors, a chalk line was drawn on the sidewalk and the interviewer given a mechanical hand counter. It was specified that he should interview every tenth person coming down the hill, with the exception of babes in arms. During those portions of the year when visitor attendance was very light, every fifth person was interviewed.

To insure random sampling, one Sunday was selected at random from all the Sundays of the month, one Saturday at random from the Saturdays, and two weekdays at random from the available weekdays. The day selected was divided into four 2-hour periods; in each period 1 hour was selected at random. The police officer to make the interviews was randomly selected from those available on the day of the sampling. The police officer asked each interviewee a single question: "Where do you live?"

The information gathered from the visitor survey was then reduced to mathematical formulae by the research statistician of the District of Columbia, and the following cumulative percentages were arrived at: District of Columbia residents, 18.8; nonresidents, 81.2 (suburban, 30; other, 51.2).

POLICE DEPARTMENT

Activities in the police department showed a marked increase in keeping with the larger visitor attendance. A new cruiser was placed in service and traveled a distance of 24,000 miles in the year. This made possible more rigid traffic-law enforcement and resulted in an increase in the number of arrests for traffic violations.

Sgt. D. B. Bell and Sgt. E. A. King attended and graduated from the Metropolitan Police Academy in March.

Lt. C. E. Brink, Sgt. E. A. King, Pvts. M. J. Devlin, H. J. Moore, and D. E. Trautman attended the monthly sessions of the Law Enforcement Institute at the University of Maryland and received certificates in June.

Sgt. A. L. Canter and Pvt. G. H. Adams attended a special course in the driver training program held by the Bureau of Departmental Operations, U.S. Civil Service Commission.

The mounted color guard consisting of five men, with Sgt. D. B. Bell in charge, participated in several parades.

The old switchboard at police headquarters was taken out of service at the administration building, and a new modern telephone system was put in operation early in November.

A new target range was completed, giving all members of the department the opportunity to practice and qualify for better marksmanship. Work on it was done by volunteer members of the force.

The total number of visitors stopping in the police station for information of various sorts was 13,262. First aid was given (principally for minor accidents such as bee stings or scraped knees) to 1,107 persons. Fifteen pairs of unclaimed eyeglasses and sunglasses were sent to the Society for the Prevention of Blindness, and six bags of unclaimed clothing and miscellaneous articles were turned over to the Goodwill Industries.

BUILDINGS AND GROUNDS

No funds were appropriated for new construction, and the regular maintenance work of patching and painting old buildings was carried on throughout the year. A number of minor improvements, however, were carried out.

A 5-ton air conditioner was installed in the feed barn for the Alaskan reindeer, and an overhead sprinkler was built in a corner of their outside yard. This shower bath runs continuously, and the reindeer obviously enjoy it, as one or more animals can usually be seen standing under it. While a fine spray of water cools their backs, they stretch their necks, tilt their heads up, and with open mouths snap at the drops of water.

A complete rewiring of the reptile house was completed, and re-wiring and a new system of lighting were installed in the monkey house. Pilot models of radiant heat were put in the floors of three shelters for hoofed stock.

A shelter, constructed in 1893 for a small herd of llamas and used in recent years for elk, was remodeled into a stable for the three police horses.

The murals in the Zoo Park Restaurant were given a thorough cleaning under the supervision of the artist Domenico Mortellito, of Wilmington, Del. The murals, designed by Mr. Mortellito in 1940 on carved, lacquered battleship linoleum, depict Noah's Ark above the fireplace and animals marching two by two around all four walls. They had darkened through the years, but may now be seen in their original glowing colors.

The work of the gardener's force consisted mainly of removing dead trees, which are a menace to both animals and visitors, and replacing them with young trees. In all, 226 trees were cut down, and 153 were limbed and topped. Stands of grass in several enclosures were thriving before the animals were moved in, and efforts are now being made to maintain the grass. Work continued on the new service road, with grading, ditching, and general maintenance, and the bank has been terraced with logs, brush reforestation, and grass seeding. Vines, weeds, and trees on or around two-thirds of the Zoo boundary were cut and trimmed. A nursery consisting of nearly 5,000 young

trees, mostly evergreens, was cared for by the gardener's force. Three men attended the Fire School at General Services Administration, three attended horticultural classes at the National Bureau of Standards, and four took the first-aid course.

PLANS FOR THE FUTURE

A new office to replace the 155-year-old "mansion" is imperative. The present administration building, while a historic landmark, is not suited to the purpose for which it is being used, nor is it safe, being honeycombed with termites and rotted from dampness. A modern building, with properly arranged offices, library stacks and shelves, a conference room, and a small laboratory, is badly needed.

The facilities at the National Zoological Park are based on antiquated installations and should be modernized, starting with such basic necessities as water, electricity, sewage, and heating. It is hoped that a master plan can be drawn for the Zoo so that all future construction and work may be coordinated.

Respectfully submitted.

THEODORE H. REED, *Director.*

Dr. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

Report on the Canal Zone Biological Area

SIR: It gives me pleasure to present herewith the annual report on the Canal Zone Biological Area for the fiscal year ended June 30, 1960.

SCIENTISTS, STUDENTS, AND OBSERVERS

Following is the list of 39 scientists, students, and observers who visited Barro Colorado Island last year, and stayed for several days, in order to conduct scientific research or observe the wildlife of the area. Twenty-seven other scientific visitors each spent a day and a night on the island. In addition, scientists of other research and technical organizations in the Canal Zone and the Republic of Panama made use of station facilities.

<i>Name</i>	<i>Principal interest</i>
Bennett, Mr. and Mrs. Charles, Jr., University of California, Los Angeles.	Temperature and humidity, gradients in forest.
Biaufuss, Arnold, Chicago, Ill.	Wildlife observation.
Boyajian, Edward, Pennsylvania State University, University Park, Pa.	Birds.
Brattstron, Dr. B., Adelphi University, Garden City, N.Y.	Reptiles and amphibians.
Brown, Dr. W. L., Jr., Harvard University, Cambridge, Mass.	Ants.
Carpenter, Dr. C. R., Pennsylvania State University, University Park, Pa.	Howler monkeys.
Carpenter, Lane, Pennsylvania State University, University Park, Pa.	Assistant to Dr. Carpenter.
Cox, George, University of Illinois, Urbana, Ill.	Tropical bird physiology.
Cumming, R. B., University of Florida, Gainesville, Fla.	Insects.
Eastman, Whitney, Minneapolis, Minn.	Birds.
Edens, Mrs. LaPrelle, Minneapolis, Minn.	Birds.
Edwards, Dr. E. P., Amherst, Va.	Birds.
Eisenmann, Dr. Eugene, New York City.	Birds.

<i>Name</i>	<i>Principal interest</i>
Elms, Alan, Pennsylvania State University, University Park, Pa.	Assistant to Dr. Carpenter.
Gasteiger, Dr. E. L., University of Rochester, Rochester, N.Y.	Comparative physiology.
Gersh, Dr. Isidore, University of Chicago, Chicago, Ill.	Wildlife observation.
Griffin, Dr. D. R., Harvard University, Cambridge, Mass.	Bats.
Groner, Mrs. Dorothy E., Los Angeles, Calif.	Birds.
Kendeigh, Dr. and Mrs. S. Charles, University of Illinois, Urbana, Ill.	Tropical bird physiology.
Kerr, Col. David, Arlington, Va.	Wildlife observation.
Kuehn, Robert, University of California, Berkeley.	Howler monkeys.
Linford, Dr. J. B., Oakland, Calif.	Wildlife observation.
Mason, Dr. W. A., Pennsylvania State University, University Park, Pa.	Howler monkeys.
McCluskey, Dr. Elwood, Harvard University, Cambridge, Mass.	Ants.
McCue, Dr. J. H. G., Massachusetts Institute of Tech- nology, Cambridge, Mass.	Bats.
McKittrick, T.H., Blairstown, N.J.	Birds.
Metzuda, Dr. Japan.	Entomology.
Peterman, Dan, Pennsylvania State University, University Park, Pa.	Assistant to Dr. Carpenter.
Petkins, Mrs. S., Gorgas Memorial Laboratory, Panama.	Fruit flies.
Ryan, Richard, New Shrewsbury, N.J.	Birds.
Smith, John, Harvard University, Cambridge, Mass.	Flycatchers.
Southwick, Dr. C. R., Pennsylvania State University, University Park, Pa.	Howler monkeys.
Stuart, Alastair, Harvard University, Cambridge, Mass.	Termite behavior.
Warren, James, University of California, Los Angeles.	Reptiles and amphibians.
Wessenberg, Dr. Harry, San Francisco State College, San Francisco, Calif.	Tropical diseases and study on the opu- linid protozoa of anurans.

<i>Name</i>	<i>Principal interest</i>
Worley, Dr. L. G., Brooklyn College, New York.	Wildlife observation.
Zimmerman, John, University of Illinois, Urbana, Ill.	Tropical bird physiology.

VISITORS

Approximately 209 visitors were permitted to visit the island for a day.

RAINFALL

During the dry season (January through April) of the calendar year 1959, rains of 0.01 inch or more fell during 19 days (34 hours) and amounted to 1.91 inches, as compared to 19.31 inches during 1958. During the wet season of 1959 (May through December), rains of 0.01 inch or more fell on 182 days (691 hours) and amounted to 92.97 inches, as compared to 80.89 inches during 1958. Total rainfall for the year was 94.88 inches. During 35 years of record, the wettest year was 1935 with 143.42 inches, and the driest year was 1930 with only 76.57 inches. March was the driest month of 1959 (0.11 inch) and December the wettest (24.41 inches). The maximum records for short periods were: 5 minutes: 1.30 inches; 10 minutes: 1.65 inches; 1 hour: 4.11 inches; 2 hours: 6.33 inches; 24 hours: 10.87 inches.

TABLE 1.—*Annual rainfall, Barro Colorado Island, C.Z.*

Year	Total inches	Station average	Year	Total inches	Station average
1925.....	104.37	-----	1943.....	120.29	109.20
1926.....	118.22	113.56	1944.....	111.96	109.30
1927.....	116.36	114.68	1945.....	120.42	109.84
1928.....	101.52	111.35	1946.....	87.38	108.81
1929.....	87.84	106.56	1947.....	77.92	107.49
1930.....	76.57	101.51	1948.....	83.16	106.43
1931.....	123.30	104.69	1949.....	114.86	106.76
1932.....	113.52	105.76	1950.....	114.51	107.07
1933.....	101.73	105.32	1951.....	112.72	107.28
1934.....	122.42	107.04	1952.....	97.68	106.94
1935.....	143.42	110.35	1953.....	104.97	106.87
1936.....	93.88	108.98	1954.....	105.68	106.82
1937.....	124.13	110.12	1955.....	114.42	107.09
1938.....	117.09	110.62	1956.....	114.05	107.30
1939.....	115.47	110.94	1957.....	97.97	106.98
1940.....	86.51	109.43	1958.....	100.20	106.70
1941.....	91.82	108.41	1959.....	94.88	106.48
1942.....	111.10	108.55			

TABLE 2.—*Comparison of 1958 and 1959 rainfall, Barro Colorado Island (inches)*

Month	Total		Station average	Years of record	1959 excess or deficiency	Accumulated excess or deficiency
	1958	1959				
January.....	4.26	0.32	2.15	34	-1.83	-----
February.....	7.34	.15	1.38	34	-1.23	-3.06
March.....	2.98	.11	1.18	34	-1.07	-4.13
April.....	4.73	1.33	2.97	35	-1.64	-5.77
May.....	12.22	8.89	10.85	35	-1.96	-7.73
June.....	8.89	8.29	10.82	35	-2.53	-10.26
July.....	9.54	8.86	11.63	35	-2.77	-13.03
August.....	12.35	8.62	12.36	35	-3.74	-16.77
September.....	10.64	14.69	10.19	35	+4.50	-12.27
October.....	15.42	9.03	13.90	35	-4.87	-17.14
November.....	7.16	10.18	18.21	35	-8.03	-25.17
December.....	4.67	24.41	10.84	35	+13.57	-11.60
Year.....	100.20	94.88	106.48	-----	-----	-11.60
Dry season.....	19.31	1.91	7.68	-----	-----	-5.77
Wet season.....	80.89	92.97	98.80	-----	-----	-5.83

BUILDINGS, EQUIPMENT, AND IMPROVEMENTS

The most unusual event on Barro Colorado Island during the past year was a series of landslides on December 7, 1959, after five days of nearly continuous rain.

Before the landslides occurred, improvement and expansion of the station facilities were proceeding according to plan: the remodeling of Chapman House had been completed; new cages and aviaries had been constructed; and plans had been drawn for remodeling the laboratory space in the new laboratory building and the living facilities in the old laboratory building. Although this progress was interrupted by the landslides, fortunately no one was injured and little equipment was destroyed; one major slide and two minor ones occurred in the station area itself and numerous others occurred in other parts of the island but the only items damaged beyond repair were two large hygrothermographs and one hygrograph, and one large aviary and pond for water birds.

The slides did, however, alter the topography of the station area, necessitating the following program of repair and reconstruction:

Demolition and re-erection of Barbour House and of one house used as quarters for the laborers.

Dredging of the channels leading to the station boat dock.

Relocation of several poles supporting electrical cables.

Soil-conservation planting of trees and shrubs in the station area and the addition of several new drainage ditches.

In addition to repairing the damages from the landslides, both of the generators and the launch *Snook* were partially overhauled and the usual maintenance tasks were continued.

OTHER ACTIVITIES

The Resident Naturalist continued his research, assisted by David Fairchild II and James Ambrose, on the behavior of several groups of tropical birds and monkeys. The National Science Foundation awarded a grant to the Resident Naturalist for a study of the behavior of tropical procyonid and mustelid carnivores.

The program of internships for graduate students was continued. John H. Kaufmann, of the University of California at Los Angeles, completed research on various aspects of the behavior and ecology of the coatimundi and secured data on some other mammals on both Barro Colorado Island and the mainland. John Ebinger, of Yale University, began to collect botanical specimens and reorganize the station herbarium, which has long been in poor condition, and this reorganization will be an extremely valuable addition to the station facilities.

Collection of data for Dr. Charles F. Bennett's study of temperature and humidity gradients in the forest on Barro Colorado Island was completed in December of 1959.

The expansion of the library continued. Work on bringing the catalog up to date, processing new acquisitions, and preparing books for binding is now being undertaken.

ACKNOWLEDGMENTS

The Canal Zone Biological Area can operate only with the excellent cooperation of the Canal Zone Government and the Panama Canal Company. Thanks are due especially to the Executive Secretary, Paul Runnestrand, and his staff, the Customs and Immigration officials, and the Police Division. The technical advice and assistance provided by P. Alton White, Chief of the Dredging Division, and members of his staff, by C. C. Soper of the Eastman Kodak Co., and by Lt. Boynton and other members of the Signal Corps Meteorological Team No. 2, were also invaluable.

Respectfully submitted.

MARTIN H. MOYNIHAN,
Resident Naturalist.

Dr. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

Report on the International Exchange Service

SIR: I have the honor to submit the following report on the activities of the International Exchange Service for the fiscal year ended June 30, 1960:

The Smithsonian Institution is the official United States agency for the exchange with other nations of governmental, scientific, and literary publications. The International Exchange Service, initiated more than a century ago by the Smithsonian Institution for the interchange of scientific publications between learned societies and individuals in the United States and those of foreign countries, serves as a means of developing and executing in part the broad and comprehensive objective, "the diffusion of knowledge." It was later designated by the United States Government as the agency for the transmission of official documents to selected depositories throughout the world, and it continues to execute the exchanges pursuant to conventions, treaties, and other international agreements.

The number of packages of publications received for transmission during the year was 1,141,998, an increase of 12,522 packages over the previous fiscal year. The weight of the packages received was 877,636 pounds, an increase of 110,247 pounds. The average weight of the individual package was 12.29 ounces as compared to the 10.87-ounce average for the fiscal year 1959.

Publications were received from approximately 250 domestic sources including United States Government bureaus and departments, congressional committees and members of Congress, universities, agricultural experiment stations, learned societies, organizations, and individuals for transmission to foreign addressees in more than 150 foreign countries. Publications were received from 59 foreign countries for distribution to addressees in the United States.

The publications received from foreign sources for addressees in the United States and from domestic sources for shipment abroad are classified as shown in the following table:

Classification	Packages		Weight	
	<i>Number</i>	<i>Number</i>	<i>Pounds</i>	<i>Pounds</i>
United States parliamentary documents received for transmission abroad.....	672, 565	-----	327, 142	-----
Publications received in return for parliamentary documents.....	-----	6, 482	-----	9, 483
United States departmental documents received for transmission abroad.....	226, 511	-----	239, 316	-----
Publications received in return for departmental documents.....	-----	4, 531	-----	11, 167
Miscellaneous scientific and literary publications received for transmission abroad.....	178, 345	-----	202, 324	-----
Miscellaneous scientific and literary publications received from abroad for distribution in the United States.....	-----	53, 564	-----	88, 204
Total.....	1, 077, 421	64, 577	768, 782	108, 854
Grand total.....	1, 141, 998		877, 636	

The packages of publications are forwarded to the exchange bureaus of foreign countries by freight or, where shipment by such means is impractical, to the foreign addressees by direct mail. Distribution in the United States of the publications received through the foreign exchange bureaus is accomplished primarily by mail, but by other means when more economical. The number of cases shipped to the foreign exchange bureaus was 3,449, or 609 more than for the previous year. Of these cases 993 were for depositories of full sets of United States Government documents, these publications being furnished in exchange for the official publications of foreign governments which are received for deposit in the Library of Congress.

The total weight of the packages transmitted during the year amounted to 870,784 pounds, which was 86,213 pounds more than was transmitted in the previous fiscal year. There was allocated to the International Exchange Service for ocean and domestic freight \$35,052.54. With this amount it was possible to effect the shipment of 575,163 pounds. The weight of packages forwarded by mail and by means other than freight was 295,621 pounds. Approximately 8,427 pounds of the full sets of United States Government documents accumulated during the year because the Library of Congress had requested suspension of shipment to certain foreign depositories.

During the year, there was an increase of 10 percent in ocean freight rates. The transportation cost for hauling books and periodicals to the Baltimore piers remained at the 1959 level.

Shipments are made to Taiwan. No shipments are made to the mainland of China, North Korea, and Communist-controlled areas of Viet-Nam.

FOREIGN DEPOSITORIES OF GOVERNMENTAL DOCUMENTS

The number of sets of U.S. official publications received by the Exchange Service for transmission abroad in return for the official publications sent by foreign governments for deposit in the Library of Congress is now 106 (62 full and 44 partial sets), listed below. Changes that occurred during the year are shown in the footnotes.

DEPOSITORIES OF FULL SETS

- ARGENTINA: División Biblioteca, Ministerio de Relaciones Exteriores y Culto, Buenos Aires.
- AUSTRALIA: Commonwealth National Library, Canberra.
- NEW SOUTH WALES: Public Library of New South Wales, Sydney.
- QUEENSLAND: Parliamentary Library, Brisbane.
- SOUTH AUSTRALIA: Public Library of South Australia, Adelaide.
- TASMANIA: Parliamentary Library, Hobart.
- VICTORIA: Public Library of Victoria, Melbourne.
- WESTERN AUSTRALIA: State Library, Perth.
- AUSTRIA: Administrative Library, Federal Chancellery, Vienna.
- BRAZIL: Biblioteca Nacional, Rio de Janeiro.
- BULGARIA: Bulgarian Bibliographical Institute, Sofia.¹
- BURMA: Government Book Depot, Rangoon.
- CANADA: Library of Parliament, Ottawa.
- MANITOBA: Provincial Library, Winnipeg.
- ONTARIO: Legislative Library, Toronto.
- QUEBEC: Library of the Legislature of the Province of Quebec.
- CEYLON: Department of Information, Government of Ceylon, Colombo.
- CHILE: Biblioteca Nacional, Santiago.
- CHINA: National Central Library, Taipei, Taiwan.
- National Chengchi University, Taipei, Taiwan.
- COLOMBIA: Biblioteca Nacional, Bogotá.
- COSTA RICA: Biblioteca Nacional, San José.
- CUBA: Ministerio de Estado, Canje Internacional, Habana.
- CZECHOSLOVAKIA: University Library, Prague.
- DENMARK: Institut Danais des Échanges Internationaux, Copenhagen.
- EGYPT: Bureau des Publications, Ministère des Finances, Cairo.
- FINLAND: Parliamentary Library, Helsinki.
- FRANCE: Bibliothèque Nationale, Paris.
- GERMANY: Deutsche Staatsbibliothek, Berlin.
- Free University of Berlin, Berlin-Dahlem.
- Parliamentary Library, Bonn.
- GREAT BRITAIN:
- ENGLAND: British Museum, London.
- LONDON: London School of Economics and Political Science. (Depository of the London County Council.)
- HUNGARY: Library of Parliament, Budapest.¹

¹ Shipment suspended.

INDIA : National Library, Calcutta.

Central Secretariat Library, New Delhi.

Parliament Library, New Delhi.

INDONESIA : Ministry for Foreign Affairs, Djakarta.

IRELAND : National Library of Ireland, Dublin.

ISRAEL : State Archives and Library, Hakirya, Jerusalem.

ITALY : Ministero della Pubblica Istruzione, Rome.

JAPAN : National Diet Library, Tokyo.²

MEXICO : Secretaría de Relaciones Exteriores, Departamento de Información para el Extranjero México, D.F.

NETHERLANDS : Royal Library, The Hague.

NEW ZEALAND : General Assembly Library, Wellington.

NORWAY : Utenriksdepartementets Bibliothek, Oslo.

PERU : Sección de Propaganda y Publicaciones, Ministerio de Relaciones Exteriores, Lima.

PHILIPPINES : Bureau of Public Libraries, Department of Education, Manila.

POLAND : Bibliothèque Nationale, Warsaw.¹

PORTUGAL : Biblioteca Nacional, Lisbon.

SPAIN : Biblioteca Nacional, Madrid.

SWEDEN : Kungliga Biblioteket, Stockholm.

SWITZERLAND : Bibliothèque Centrale Fédérale, Berne.

TURKEY : National Library, Ankara.

UNION OF SOUTH AFRICA : State Library, Pretoria, Transvaal.

UNION OF SOVIET SOCIALIST REPUBLICS : All-Union Lenin Library, Moscow.

UNITED NATIONS : Library of the United Nations, Geneva, Switzerland.

URUGUAY : Oficina de Canje Internacional de Publicaciones, Montevideo.

VENEZUELA : Biblioteca Nacional, Caracas.

YUGOSLAVIA : Bibliografski Institut, Belgrade.²

DEPOSITORIES OF PARTIAL SETS

AFGHANISTAN : Library of the Afghan Academy, Kabul.

BELGIUM : Bibliothèque Royale, Bruxelles.²

BOLIVIA : Biblioteca del Ministerio de Relaciones Exteriores y Culto, La Paz.

BRAZIL : MINAS GERIAS : Departamento Estadual de Estatística, Belo Horizonte.

BRITISH GUIANA : Government Secretary's Office, Georgetown, Demerara.

CANADA :

ALBERTA : Provincial Library, Edmonton.

BRITISH COLUMBIA : Provincial Library, Victoria.

NEW BRUNSWICK : Legislative Library, Fredericton.

NEWFOUNDLAND : Department of Provincial Affairs, St. John's.

NOVA SCOTIA : Provincial Secretary of Nova Scotia, Halifax.

SASKATCHEWAN : Legislative Library, Regina.

DOMINICAN REPUBLIC : Biblioteca de la Universidad de Santo Domingo, Ciudad Trujillo.

ECUADOR : Biblioteca Nacional, Quito.

EL SALVADOR :

Biblioteca Nacional, San Salvador.

Ministerio de Relaciones Exteriores, San Salvador.

GREECE : National Library, Athens.

GUATEMALA : Biblioteca Nacional, Guatemala.

¹ Receives two sets.

² Changed from a full to a partial set.

HAITI : Bibliothèque Nationale, Port-au-Prince.

HONDURAS :

Biblioteca Nacional, Tegucigalpa.

Ministerio de Relaciones Exteriores, Tegucigalpa.

IOELAND : National Library, Reykjavik.

INDIA :

BOMBAY : Secretary to the Government, Bombay.

BIHAR : Revenue Department, Patna.

KERALA : Kerala Legislature Secretariat, Trivandrum.*

UTTAR PRADESH :

University of Allahabad, Allahabad.

Secretariat Library, Lucknow.

WEST BENGAL : Library, West Bengal Legislative Secretariat, Assembly House, Calcutta.

IRAN : Imperial Ministry of Education, Tehran.

IRAQ : Public Library, Baghdad.

JAMAICA :

Colonial Secretary, Kingston.

University College of the West Indies, St. Andrew.

LEBANON : American University of Beirut, Beirut.

LIBERIA : Department of State, Monrovia.

MALAYA : Federal Secretariat, Federation of Malaya, Kuala Lumpur.

MALTA : Minister for the Treasury, Valletta.

NICARAGUA : Ministerio de Relaciones Exteriores, Managua.

PAKISTAN : Central Secretariat Library, Karachi.

PANAMA : Ministerio de Relaciones Exteriores, Panamá.

PARAGUAY : Ministerio de Relaciones Exteriores, Sección Biblioteca, Asunción.

PHILIPPINES : House of Representatives, Manila.

SCOTLAND : National Library of Scotland, Edinburgh.

SIAM : National Library, Bangkok.

SINGAPORE : Chief Secretary, Government Offices, Singapore.

SUDAN : Gordon Memorial College, Khartoum.

INTERPARLIAMENTARY EXCHANGE OF THE OFFICIAL JOURNAL

There are now being sent abroad 87 copies of the Federal Register and 97 copies of the Congressional Record. This is an increase over the preceding year of two copies of the Federal Register and of two copies of the Congressional Record. The countries to which these journals are being forwarded are given in the following list :

DEPOSITORIES OF CONGRESSIONAL RECORD AND FEDERAL REGISTER

ARGENTINA :

Biblioteca de la H. Legislatura de Mendoza, Mendoza.*

Biblioteca del Poder Judicial, Mendoza.*

Boletín Oficial de la República Argentina, Ministerio de Justicia e Instrucción Pública, Buenos Aires.

Cámara de Diputados Oficina de Información Parlamentaria, Buenos Aires.

* Added during the year.

* Congressional Record only.

* Federal Register only.

AUSTRALIA:

Commonwealth National Library, Canberra.

NEW SOUTH WALES: Library of Parliament of New South Wales, Sydney.

QUEENSLAND: Chief Secretary's Office, Brisbane.

VICTORIA: Public Library of Victoria, Melbourne.⁶

WESTERN AUSTRALIA: Library of Parliament of Western Australia, Perth.

BRAZIL: Secretaria de Presidencia, Rio de Janeiro.⁵

BRITISH HONDURAS: Colonial Secretary, Belize.

CAMBODIA: Ministry of Information, Phnom Penh.⁴

CANADA:

Clerk of the Senate, Houses of Parliament, Ottawa.

Library of Parliament, Ottawa.

CEYLON: Ceylon Ministry of Defense and External Affairs, Colombo.⁵CHILE: Biblioteca del Congreso Nacional, Santiago.⁵

CHINA:

Legislative Yuan, Taipei, Taiwan.⁵

Taiwan Provincial Government, Taipei, Taiwan.

CUBA:

Biblioteca del Capitolio, Habana.

Biblioteca Pública Panamericana, Habana.⁶CZECHOSLOVAKIA: Československa Akademie Ved, Prague.⁵EGYPT: Ministry of Foreign Affairs, Egyptian Government, Cairo.⁵

FRANCE:

Bibliothèque Assemblée Nationale, Paris.

Bibliothèque Conseil de la République, Paris.

Library, Organization for European Economic Cooperation, Paris.⁶Research Department, Council of Europe, Strasbourg.⁵Service de la Documentation Étrangère, Assemblée Nationale, Paris.⁶

GERMANY:

Amerika Institut der Universität München, München.⁵

Archiv, Deutscher Bundestag, Bonn.

Bibliothek der Instituts für Weltwirtschaft an der Universität Kiel, Kiel-Wik.

Bibliothek Hessischer Landtag, Wiesbaden.⁵Der Bayrische Landtag, Munich.^{5, 7}Deutsches Institut für Rechtswissenschaft, Potsdam-Babelsberg II.⁶Deutscher Bundesrat, Bonn.⁵Deutscher Bundestag, Bonn.⁵

Hamburgisches Welt-Wirtschafts-Archiv, Hamburg.

GHANA: Chief Secretary's Office, Accra.⁵

GREAT BRITAIN:

Department of Printed Books, British Museum, London.

House of Commons Library, London.⁵N.P.P. Warehouse, H.M. Stationery Office, London.^{5, 6}

Printed Library of the Foreign Office, London.

Royal Institute of International Affairs, London.⁵

GREECE: Bibliothèque, Chambre des Députés Hellénique, Athens.

GUATEMALA: Biblioteca de la Asamblea Legislativa, Guatemala.

⁷ Three copies.⁶ Two copies.

HAITI: Bibliothèque Nationale, Port-au-Prince.

HONDURAS: Biblioteca del Congreso Nacional, Tegucigalpa.

HUNGARY: National Library, Budapest.

INDIA:

Civil Secretariat Library, Lucknow, United Provinces.⁶

Indian Council of World Affairs, New Delhi.⁵

Jammu and Kashmir Constituent Assembly, Srinagar.⁵

Legislative Assembly, Government of Assam, Shillong.⁵

Legislative Assembly Library, Lucknow, United Provinces.

Kerala Legislature Secretariat, Trivandrum.⁵

Madras State Legislature, Madras.⁵

Parliament Library, New Delhi.

Servants of Indian Society, Poona.⁵

IRELAND: Dail Eireann, Dublin.

ISRAEL: Library of the Knesset, Jerusalem.

ITALY:

Biblioteca Camera dei Deputati, Rome.

Biblioteca del Senato della Repubblica, Rome.

International Institute for the Unification of Private Law, Rome.⁶

Periodicals Unit, Food and Agriculture Organization of the United Nations, Rome.⁶

JAPAN:

Library of the National Diet, Tokyo.

Ministry of Finance, Tokyo.

JORDAN: Parliament of the Hashemite Kingdom of Jordan, Amman.⁵

KOREA: Library, National Assembly, Seoul.

LUXEMBOURG: Assemblée Commune de la C.E.C.A., Luxembourg.

MEXICO:

Dirección, General Information, Secretaría de Gobernación, Mexico, D.F.

Biblioteca Benjamin Franklin, México, D.F.

AGUASCALIENTES: Gobernador del Estado de Aguascalientes, Aguascalientes.

BAJA CALIFORNIA: Gobernador del Distrito Norte, Mexicali.

CAMPECHE: Gobernador del Estado de Campeche, Campeche.

CHIAPAS: Gobernador del Estado de Chiapas, Tuxtla Gutiérrez.

CHICHUAHUA: Gobernador del Estado de Chihuahua, Chihuahua.

COAHUILA: Periódico Oficial del Estado de Coahuila, Palacio de Gobierno, Saltillo.

COLIMA: Gobernador del Estado de Colima, Colima.

GUANAJUATO: Secretaría General de Gobierno del Estado, Guanajuato.⁶

JALISCO: Biblioteca del Estado, Guadalajara.

MÉXICO: Gaceta del Gobierno, Toluca.

MICHOACÁN: Secretaría General de Gobierno del Estado de Michoacán, Morelia.

MORELOS: Palacio de Gobierno, Cuernavaca.

NAYARIT: Gobernador de Nayarit, Tepic.

NUÉVO LEÓN: Biblioteca del Estado, Monterrey.

OAXACA: Periódico Oficial, Palacio de Gobierno, Oaxaca.⁶

PUEBLA: Secretaría General de Gobierno, Puebla.

QUERÉTARO: Secretaría General de Gobierno, Sección de Archivo, Querétaro.

SINALOA: Gobernador del Estado de Sinaloa, Culiacán.

Mexico—Continued

SONORA: Gobernador del Estado de Sonora, Hermosillo.

TAMAULIPAS: Secretaría General de Gobierno, Victoria.

VERACRUZ: Gobernador del Estado de Veracruz, Departamento de Gobernación y Justicia, Jalapa.

YUCATÁN: Gobernador del Estado de Yucatán, Mérida.

NETHERLANDS: Koninklijke Bibliotheek, The Hague.⁴

NEW ZEALAND: General Assembly Library, Wellington.

NORWAY: Library of the Norwegian Parliament, Oslo.

PANAMA: Biblioteca Nacional, Panama City.⁵

PHILIPPINES: House of Representatives, Manila.

POLAND: Kancelaria Rady, Panstwa, Biblioteka Sejmowa, Warsaw.

PORTUGUESE TIMOR: Repartição Central de Administração Civil, Dill.⁶

RHODESIA AND NYASALAND: Federal Assembly, Salisbury.⁷

RUMANIA: Biblioteca Centrala de Stat RPR, Bucharest.

SPAIN: Boletín Oficial del Estado, Presidencia del Gobierno, Madrid.⁸

SWITZERLAND: Bibliothèque, Bureau International du Travail, Geneva.⁹

International Labor Office, Geneva.¹⁰

Library, United Nations, Geneva.

Togo: Ministère d'Etat, de l'Interieur, de l'Information et de la Presse, Lome.⁴

UNION OF SOUTH AFRICA:

CAPE OF GOOD HOPE: Library of Parliament, Cape Town.

TRANSSVAAL: State Library, Pretoria.

UNION OF SOVIET SOCIALIST REPUBLICS: Fundamental'nnaia Biblioteka Obschestvennykh Nauk, Moscow.

URUGUAY: Diario Oficial, Calle Florida 1178, Montevideo.

YUGOSLAVIA: Bibliografski Institut FNRJ, Belgrade.⁹

FOREIGN EXCHANGE SERVICES

Exchange publications for addressees in the countries listed below are forwarded by freight to the exchange services of those countries. Exchange publications for addressees in other countries are forwarded directly by mail.

LIST OF EXCHANGE SERVICES

AUSTRIA: Austrian National Library, Vienna.

BELGIUM: Service des Échanges Internationaux, Bibliothèque Royale de Belgique, Bruxelles.

CHINA: National Central Library, Taipei, Taiwan.

CZECHOSLOVAKIA: Bureau of International Exchanges, University Library, Prague.

DENMARK: Institut Danois des Échanges Internationaux, Bibliothèque Royale, Copenhagen.

EGYPT: Government Press, Publications Office, Bulaq, Cairo.

FINLAND: Delegation of the Scientific Societies, Helsinki.

FRANCE: Service des Échanges Internationaux, Bibliothèque Nationale, Paris.

GERMANY (Eastern): Deutsche Staatsbibliothek, Berlin.

GERMANY (Western): Deutsche Forschungsgemeinschaft, Bad Godesberg.

- HUNGARY: National Library, Széchenyi, Budapest.
 INDIA: Government Printing and Stationery, Bombay.
 INDONESIA: Minister of Educaiton, Djakarta.
 ISRAEL: Jewish National and University Library, Jerusalem.
 ITALY: Ufficio degli Scambi Internazionali, Ministero della Pubblica Istruzione, Rome.
 JAPAN: Division for Interlibrary Services, National Diet Library, Tokyo.
 KOREA: Korean Library Association, Seoul.
 NETHERLANDS: International Exchange Bureau of the Netherlands, Royal Library, The Hague.
 NEW SOUTH WALES: Public Library of New South Wales, Sydney.
 NEW ZEALAND: General Assembly Library, Wellington.
 NORWAY: Service Norvégien des Échanges Internationaux, Bibliothèque de l'Université Royale, Oslo.
 PHILIPPINES: Bureau of Public Libraries, Department of Education, Manila.
 POLAND: Service Polonais des Échanges Internationaux, Bibliothèque Nationale, Warsaw.
 PORTUGAL: Secção de Trocas Internacionais, Biblioteca Nacional, Lisbon.
 QUEENSLAND: Bureau of International Exchange of Publications, Chief Secretary's Office, Brisbane.
 ROMANIA: International Exchange Service, Biblioteca Centrala de Stat, Bucharest.
 SOUTH AUSTRALIA: South Australian Government Exchanges Bureau, Government Printing and Stationery Office, Adelaide.
 SPAIN: Junta de Intercambio y Adquisición de Libros y Revistas para Bibliotecas Públicas, Ministerio de Educación Nacional, Madrid.
 SWEDEN: Kungliga Biblioteket, Stockholm.
 SWITZERLAND: Service Suisse des Échanges Internationaux, Bibliothèque Centrale Fédérale, Palais Fédéral, Berne.
 TASMANIA: Secretary of the Premier, Hobart.
 TURKEY: National Library, Ankara.
 UNION OF SOUTH AFRICA: Government Printing and Stationery Office, Cape Town.
 UNION OF SOVIET SOCIALIST REPUBLICS: Bureau of Book Exchange, State Lenin Library, Moscow.
 VICTORIA: Public Library of Victoria, Melbourne.
 WESTERN AUSTRALIA: State Library, Perth.
 YUGOSLAVIA: Bibliografski Institut FNRJ, Belgrade.

Respectfully submitted.

J. A. COLLINS, *Chief.*

Dr. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

Report on the National Gallery of Art

SIR: I have the honor to submit, on behalf of the Board of Trustees, the twenty-third annual report of the National Gallery of Art, for the fiscal year ended June 30, 1960. This report is made pursuant to the provisions of section 5(d) of Public Resolution No. 14, Seventy-fifth Congress, first session, approved March 24, 1937 (50 Stat. 51).

ORGANIZATION

The statutory members of the Board of Trustees of the National Gallery of Art are the Chief Justice of the United States, the Secretary of State, the Secretary of the Treasury, and the Secretary of the Smithsonian Institution, *ex officio*. The five general trustees continuing in office during the fiscal year ended June 30, 1960, were Duncan Phillips, Ferdinand Lammot Belin, Chester Dale, Paul Mellon, and Rush H. Kress. On May 5, 1960, Chester Dale was reelected by the Board of Trustees to serve as President of the Gallery and Ferdinand Lammot Belin was reelected Vice President.

The executive officers of the Gallery as of June 30, 1960, are as follows:

Huntington Cairns, Secretary-Treasurer.	Ernest R. Feidler, Administrator.
John Walker, Director.	Huntington Cairns, General Counsel.
	Perry B. Cott, Chief Curator.

The three standing committees of the Board, as constituted at the annual meeting on May 5, 1960, were as follows:

EXECUTIVE COMMITTEE

Chief Justice of the United States, Earl Warren, Chairman.	Secretary of the Smithsonian Institution, Leonard Carmichael.
Ferdinand Lammot Belin.	Paul Mellon.
Chester Dale, Vice Chairman.	

FINANCE COMMITTEE

Secretary of the Treasury, Robert B. Anderson, Chairman.	Secretary of the Smithsonian Institution, Leonard Carmichael.
Ferdinand Lammot Belin.	Paul Mellon.
Chester Dale, Vice Chairman.	

ACQUISITIONS COMMITTEE

Ferdinand Lammot Belin, Chairman.	Paul Mellon.
Duncan Phillips.	John Walker.
Chester Dale.	

PERSONNEL

On June 30, 1960, full-time Government employees on the staff of the National Gallery of Art numbered 314 as compared with 299 employees as of June 30, 1959. The U.S. Civil Service regulations govern the appointment of employees paid from appropriated public funds.

A number of employees were given training under the provisions of the Government Employees Training Act.

APPROPRIATIONS

For the fiscal year ended June 30, 1960, the Congress of the United States in the regular annual appropriation for the National Gallery of Art provided \$1,834,000 to be used for salaries and expenses in the operation and upkeep of the Gallery, the protection and care of works of art acquired by the Board of Trustees, and all administrative expenses incident thereto, as authorized by Joint Resolution of Congress approved March 24, 1937 (20 U.S.C. 71-75; 50 Stat. 51).

The following expenditures and encumbrances were incurred:

Personal services.....	\$1, 451, 909. 94
Other than personal services.....	381, 879. 06
Unobligated balance.....	211. 00
Total.....	1, 834, 000. 00

ATTENDANCE

There were 965,190 visitors to the Gallery during the fiscal year 1960, an increase of 13,582 over the total attendance of 951,608 for the fiscal year 1959. The average daily number of visitors was 2,659.

ACCESSIONS

There were 620 accessions by the National Gallery of Art as gifts, loans, or deposits during the fiscal year.

GIFTS

During the year the following gifts or bequests were accepted by the Board of Trustees:

PAINTINGS		
<i>Donor</i>	<i>Artist</i>	<i>Title</i>
Mrs. Cooper R. Drewry...	Eichholtz.....	The Ragan Sisters.
Henry Prather Fletcher...	Savage, attr. to ---	George Washington.
Col. and Mrs. Edgar W. Garbisch.	Joshua Johnston...	The Westwood Children.
Do.....	Stock.....	The Wilcox Children.
Do.....	Unknown.....	Jonathan Benham.
Do.....	do.....	Baby in Blue Cradle
Do.....	do.....	Lady in White.

<i>Donor</i>	<i>Artist</i>	<i>Title</i>
Col. and Mrs. Edgar W. Garbisch.	Unknown-----	Boy in Blue Coat.
Do-----	do-----	Child with Rocking Horse.
Do-----	do-----	Leaving the Manor House.
Do-----	do-----	Five Children of the Budd Family.
Do-----	do-----	Civil War Battle Scene.
Do-----	do-----	Little Girl and the Cat.
Do-----	do-----	Profile Portrait of a Lady in White.
Rupert L. Joseph-----	Ruisdael-----	Park with a Country House.
Mrs. Eleanor Lothrop and Gordon Abbott.	Copley-----	Colonel Fitch and His Sisters
National Gallery of Art Purchase Fund—Andrew W. Mellon Gift.	West-----	The Battle of La Hogue.
Mrs. Lillian S. Timken----	Bellini, attr. to----	Portrait of a Man.
Do-----	Boucher-----	Diana and Endymion.
Do-----	Boucher-----	The Love Letter.
Do-----	Corot-----	St. Sebastian Succored by Holy Women.
Do-----	Correggio, attr. to--	Madonna and Child with the Infant St. John.
Do-----	Cotes-----	Portrait of a Lady.
Do-----	Cotes-----	Portrait of a Lady.
Do-----	Dou-----	The Hermit.
Do-----	Drouais-----	Madame du Barry.
Do-----	Dutch School, after Ter Borch.	The Concert.
Do-----	Flemish School, Manner of Van Dyck.	Twelve Apostles.
Do-----	Fragonard-----	The Happy Family.
Do-----	French School-----	Young Woman and Man.
Do-----	French School, after Pater.	Fête Champêtre.
Do-----	French School, XVIII Century.	Divertissement.
Do-----	Fry-----	Egyptian Temple.
Do-----	Fry-----	Flock of Sheep.
Do-----	Fry-----	Shepherd and Sheep.
Do-----	Greuze-----	Girl with Birds.
Do-----	Greuze-----	Girl with Folded Arms.
Do-----	After Van Dyck----	Children of Oliver St. John, Earl of Bolingbroke.
Do-----	Henner-----	Reclining Nude.
Do-----	Herring-----	Horses.
Do-----	Italian School-----	Head of a Woman.
Do-----	Italian School-----	The Adoration of the Shep- herds.
Do-----	Lely-----	Barbara Villiers, Duchess of Cleveland.

<i>Donor</i>	<i>Artist</i>	<i>Title</i>
Mrs. Lillian S. Timken----	Moroni-----	Gian Federigo Madruzzo.
Do-----	Nattier-----	Portrait of a Lady.
Do-----	Neeffs-----	Antwerp Cathedral.
Do-----	Portuguese School--	Four-Panel Screen.
Do-----	Romney-----	Sir Archibald Campbell.
Do-----	Rubens, School of--	St. Peter.
Do-----	Rubens, School of--	Peter Paul Rubens.
Do-----	Russian School----	The Crucifixion.
Do-----	Russian School----	Christ Blessing.
Do-----	Tiepolo-----	Bacchus and Ariadne.
Do-----	Marco Tintoretto---	Pietà.
Do-----	Titian, attr. to----	Group Portrait.
Do-----	Titian, attr. to----	Self-Portrait.
Do-----	Turner-----	The Evening of the Deluge.
Do-----	Vigée-Lebrun, attr. to	Marie-Antoinette.
Do-----	Wilkie-----	Camping Gypsies.

SCULPTURE

Rupert L. Joseph-----	Epstein-----	An American Soldier.
National Gallery of Art Purchase Fund—Andrew W. Mellon Gift.	Italian, XVI Century.	Mereury.

DECORATIVE ARTS

James Hazen Hyde-----	Seventeenth-Cen- tury Tapestry.	America.
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GRAPHIC ARTS

During the year Lessing J. Rosenwald increased his gift to the Gallery by 77 additional prints and drawings.

A drawing by Bellows, "Three Figures in a Surrey," was given to the Gallery by Mrs. Andrew G. Carey, and a print by DeLaunay, after Fragonard, entitled "Les Voeux Acceptés" was purchased by the Gallery with funds derived from the Print Purchase Fund.

OTHER GIFTS

During the fiscal year 1960 gifts of money were made by The A. W. Mellon Educational and Charitable Trust, Old Dominion Foundation, Avalon Foundation, Mrs. E. C. Chadbourne, George M. and Pamela S. Humphrey Fund, and the Five Towns Foundation.

EXCHANGE OF WORK OF ART

In exchange for a print by Israhel van Meckenem entitled "The Annunciation," Lessing J. Rosenwald gave the National Gallery of Art a superior impression of the same print.

WORKS OF ART ON LOAN

The following works of art were received on loan by the Gallery:

<i>From</i>	<i>Artist</i>	<i>Title</i>
Robert Woods Bliss, Washington, D.C.	-----	16 objects of Pre-Columbian Art.
Mrs. Mellon Bruce, New York, N.Y.	Pissarro-----	Spring at Louveciennes.
Chester Dale, New York, N.Y.	Bellows-----	Blue Morning.
Do-----	Monet-----	The Seine at Giverny.
Col. and Mrs. Edgar W. Garbisch, New York, N.Y.	Polk-----	John Hart.
Do-----	---do-----	Mrs. John Hart and Daughter.
Do-----	Unknown-----	Adeline Harwood.
Do-----	---do-----	Quail.
Do-----	---do-----	Five Master.
Eugene and Agnes Meyer, Washington, D.C.	Cézanne-----	Vase of Flowers.
Do-----	---do-----	Portrait of a Sailor.
Do-----	---do-----	Le Château Noir.
Do-----	---do-----	Still Life.
Do-----	Manet-----	Do.
Do-----	Renoir-----	Man Lying on Sofa.
Do-----	---do-----	Nude.
Do-----	Dufresne-----	Still Life.

WORKS OF ART ON LOAN RETURNED

The following works of art on loan were returned during the fiscal year:

<i>To</i>	<i>Artist</i>	<i>Title</i>
Robert Woods Bliss, Washington, D.C.	-----	8 objects of Pre-Columbian art.
Chester Dale, New York, N.Y.	Bellows-----	Blue Morning.
Do-----	Monet-----	The Seine at Giverny.
Col. and Mrs. Edgar W. Garbisch, New York, N.Y.	Hayes-----	Bare Knuckles.
Do-----	J. Thomas-----	The Ship Nancy Homeward Bound.
Do-----	Unknown-----	Miss Dennison.
Do-----	---do-----	Suzanne Truax.
Do-----	---do-----	The Cat.
Do-----	---do-----	Twin Sisters.
Do-----	---do-----	Leaving the Manor House.
The Calouste Gulbenkian Foundation, Lisbon, Portugal.	-----	41 paintings, 36 pieces of sculpture, 10 works of graphic art, and 8 objects of decorative art.

<i>To</i>	<i>Artist</i>	<i>Title</i>
Miss Emily Crawford Johnson, Frederick, Md.	Vanderlyn.....	President James Monroe.
Samuel H. Kress Foundation New York, N.Y.	Andrea del Sarto....	Charity.
Eugene and Agnes Meyer, Washington, D.C.	Cézanne.....	Vase of Flowers.
Do.....	----do.....	Portrait of a Sailor.
Do.....	----do.....	Le Chateau Noir.
Do.....	----do.....	Still Life.
Do.....	Dufresne.....	Do.
Do.....	Manet.....	Do.
Do.....	Renoir.....	Man Lying on Sofa.
Do.....	----do.....	Nude.
Mr. and Mrs. Carleton Mitchell, Annapolis, Md.	Cézanne.....	Man with Crossed Arms.
Do.....	Van Gogh.....	The Stevedores.
Robert H. Thayer, New York, N.Y.	Copley.....	Harrison Gray.
Do.....	----do.....	Elizabeth Gray Otis.
Do.....	Stuart.....	Samuel Alleyne Otis.

WORKS OF ART LENT

During the fiscal year the Gallery lent the following works of art for exhibition purposes:

<i>To</i>	<i>Artist</i>	<i>Title</i>
American Federation of Arts, New York, N.Y.	Bundy.....	Vermont Lawyer.
Do.....	Unknown.....	Mahantango Valley Farm.
Corcoran Gallery of Art, Washington, D.C.	Eichholtz.....	The Ragan Sisters.
Do.....	Harding.....	Charles Carroll of Carrollton.
Do.....	Joshua Johnston...	The Westwood Children.
Do.....	Stuart.....	William Thornton.
Do.....	Stuart.....	Mrs. William Thornton.
Do.....	Sully.....	Governor Charles Ridgely of Maryland.
Do.....	Unknown.....	The End of the Hunt.
Daughters of the American Revolution, Washington, D.C.	Pine.....	General William Smallwood.
Newark Museum, Newark, N.J.	Boucher.....	Tête-a-Tête (drawing).
Smithsonian Institution, Political History Division, Washington, D.C.		The Presidents' Fan.
Woodlawn Plantation, Mt. Vernon, Va.	Polk.....	General Washington at Princeton.

EXHIBITIONS

The following exhibitions were held at the National Gallery of Art during the fiscal year 1960:

Etchings and Mezzotints from Turner's Liber Studiorum. Gift of Miss Ellen T. Bullard and from the Rosenwald Collection. Continued from previous fiscal year. June 25, 1959, to November 8, 1959.

Exhibition of recent accessions: The Tragedian by Manet and two paintings by Whistler, *Self-Portrait* and *George W. Vanderbilt*. September 6, 1959, through October 5, 1959.

American Prints Today—1959. Exhibition of 62 etchings, engravings, woodcuts, lithographs, and serigraphs, done by American artists between January 1956 and December 1958; September 15, 1959, through October 18, 1959.

Christmas Prints. From the Rosenwald Collection. December 14, 1959, to January 11, 1960.

Prints by Toulouse-Lautrec. November 9, 1959, through December 13, 1959. Reinstalled January 12, 1960, to continue into the next fiscal year.

Haniwa—Japanese Burial Mound Figures. Lent by the Japanese Government. January 10, 1960, through February 21, 1960.

Honoré Daumier. Sculpture, drawings, and lithographs by Honoré Daumier from the Rosenwald Collection. March 12, 1960, through June 26, 1960.

TRAVELING EXHIBITIONS

Rosenwald Collection.—Special exhibitions of prints and drawings from the Rosenwald Collection were circulated during the fiscal year to 28 museums, universities, schools, and art centers in the United States. In addition three exhibitions were sent to the Haus der Kunst, Munich, Germany; Belvedere Museum, Vienna, Austria; and the Oesterreichische Galerie, Vienna, Austria.

Index of American Design.—During the fiscal year 1960, 19 traveling exhibitions (988 plates) with 26 bookings were circulated to Brazil, Germany, Pakistan, and 14 States in the United States.

CURATORIAL ACTIVITIES

Under the direction of Dr. Perry B. Cott, chief curator, the curatorial department accessioned 143 gifts to the Gallery during the fiscal year 1960. Advice was given regarding 561 works of art brought to the Gallery for expert opinion and 27 visits to collections were made by members of the staff in connection with offers of gifts. About 3,100 inquiries, many of them requiring research, were answered verbally and by letter.

Miss Elizabeth Mongan, curator of graphic arts, served on the board of directors of the Print Council of America again this year. She lectured on Graphic Arts at the Norfolk Museum of Art, Currier Art Gallery, Fogg Art Museum, Louisiana State University, and Bryn Mawr College.

Dr. H. Lester Cooke, museum curator, was awarded a U.S. Government grant under the International Exchange Program and lectured in Italy from November 1959 to April 1960.

William P. Campbell, curator of painting, assisted at the judging of the Navy Department Art exhibition. John Pancoast, registrar, assisted at the judging of the exhibition for the Military District of Washington.

Dr. Katharine Shepard, assistant curator of graphic arts, served again as secretary of the Washington Society of the Archaeological Institute of America. She also was an official delegate to the general meeting of the Archaeological Institute in New York City, December 1959.

The Richter Archives received and cataloged over 260 photographs on exchange from museums here and abroad; 916 photographs were purchased, and about 10,000 reproductions clipped from magazines and catalogs were added to the Richter Archives.

RESTORATION

Francis Sullivan, resident restorer of the Gallery, made regular and systematic inspection of all works of art in the Gallery, and periodically removed dust and bloom as required. He relined 15 paintings and gave special treatment to 40. Twenty-eight paintings were X-rayed as an aid in research. Experiments were continued with the application of 27H and other synthetic varnishes developed by the National Gallery of Art Fellowship at the Mellon Institute of Industrial Research, Pittsburgh, Pa. Proofs of all color reproductions of Gallery paintings were checked and approved, and technical advice on the conservation of paintings was furnished to the public upon request.

Mr. Sullivan inspected all Gallery paintings on loan in Government buildings in Washington. He also gave advice on and special treatment to works of art belonging to other Government agencies including the White House, the Freer Gallery of Art, and the Smithsonian Institution.

PUBLICATIONS

Dr. Perry B. Cott, chief curator, contributed an article entitled "The National Gallery of Art in Washington" to *Westermanns Monatshefte*, February 1960.

Dr. Fern Rusk Shapley, assistant chief curator, contributed an article entitled "A Note on 'The Three Philosophers' by Giorgione," to *The Art Quarterly*, Autumn, 1959. She also wrote two booklets entitled "Early Italian Painting" and "Later Italian Paintings" published by the National Gallery of Art.

John Pancoast, registrar, wrote a review for *The American Scholar*, Winter, 1960.

Dr. H. Lester Cooke, museum curator, wrote two articles on American Art for *Amerika*, and the texts for 10 filmstrips on "History of Art" published by Encyclopaedia Britannica Films, Inc. He also wrote two booklets entitled "British Painting" and "French Painting of the 16th-18th Centuries."

Thomas P. Baird, museum curator, wrote the booklet entitled "Dutch Painting."

During the fiscal year 1960 the Publications Fund published 8 of what will be a series of 10 booklets on the schools of painting in the Gallery collection, each with 16 color plates and text by a staff member. These paperbound booklets, priced at 25 cents, are intended to give the general public an introduction to art history as represented in the Gallery's collection. One new catalog entitled "Paintings and Sculpture from the Kress Collection" was produced. The fifth annual series of the A. W. Mellon Lectures in the Fine Arts, "Art and Illusion," by E. H. Gombrich, published in book form, was placed on sale, as were two books written by staff members: "Benjamin West and the Taste of His Times," by Grose Evans, and "The History of Western Art," by Dr. Erwin O. Christensen.

Two new color postcards were made, as well as seven new Christmas-card subjects in color and three in black-and-white.

The Publications Fund took over distribution of the slidestrips, filmstrips, and recordings previously sold by the Educational Department and revised editions of most of these publications were produced during the year. Five sets of color slides issued by the Audubon Society reproducing Audubon prints in the Gallery collection were made available in the Information Rooms.

The growth of sales activities is indicated by the fact that 200,486 persons in fiscal year 1960 made purchases in the Gallery's Information Rooms, compared with 184,254 in fiscal year 1959.

EDUCATIONAL PROGRAM

The program of the Educational Office was carried out under the supervision of Dr. Raymond S. Stites, curator in charge of educational work. The staff lectured and conducted tours in the Gallery on the works of art in its collection.

The attendance for the General Tours, Tours of the Week, and Picture of the Week talks, totaled 40,607 persons, and that of the auditorium lectures on Sunday afternoons totaled 13,005 persons.

Appointments were arranged for 313 special lectures, tours, and conferences. A total of 10,418 persons was served in this manner. These included groups from Government Agencies, the Armed Forces,

foreign students, religious organizations, Girl Scouts, 4-H Clubs, conventions, and local chapters of women's organizations.

The program of training volunteer docents continued, and during the fiscal year 1960 special instruction was given to 100 volunteers. By special arrangement with the school systems of the District of Columbia and surrounding counties of Maryland and Virginia these volunteers conducted tours for 1,266 classes with a total of 46,584 children, an increase of 6,229 children visiting the National Gallery of Art.

The staff of the Educational Office delivered six lectures in the auditorium on Sunday afternoons and 30 lectures were given by guest speakers. Wilmarth Sheldon Lewis delivered the Ninth Annual Series of the A. W. Mellon Lectures in the Fine Arts, beginning on February 21, for six consecutive Sundays. His subject was Horace Walpole.

The Educational Office now has 10 sets of traveling exhibitions and an exhibition publicizing teachers' aids offered by the department. These are lent free of charge except for transportation costs to schools, clubs, libraries, and universities throughout the country. The exhibitions were circulated to 42 such places with an estimated total of 20,000 persons viewing them.

Fifteen copies of the film "Your National Gallery of Art" were on permanent loan in distribution centers; three copies of the new film "Art in the Western World" were circulated through the Educational Office to 44 borrowers. This latter film is sold through Encyclopaedia Britannica Films, Inc. A few copies of a film, made from a television show, entitled "Time Enough To See a World" have been deposited in the Educational Office.

The slide library has a total of 40,624 slides in the permanent and lending collections. During the year 3,018 slides were added to the collection; 1,118 borrowers used 41,601 slides from the lending collection.

A number of slide lectures consisting of color slides and a lecture text are available to schools, clubs, and churches on a loan basis.

Members of the staff participated in outside lectures, and taught night classes in the local universities. Four new slide lectures were completed, and illustrated booklets on three schools of painting represented in the National Gallery of Art were completed by the staff members.

A printed calendar of events announcing the Gallery's activities and publications was prepared by the Educational Office and distributed monthly to a mailing list of 7,200 names.

The staff members prepared and delivered 16 new 10-minute talks over radio station WGMS during the intermissions of the Sunday evening concert broadcasts.

LIBRARY

Important contributions to the library recorded by Miss Ruth E. Carlson, librarian, and her staff included 398 books, pamphlets, periodicals, and subscriptions, and a group of 916 photographs, purchased from private funds. Government funds were used for the purchase of 12 books and 26 periodicals and for the binding of 177 volumes of periodicals. Gifts to the library included 665 books and pamphlets; 993 books, pamphlets, periodicals, and bulletins were received through exchange arrangements or as complimentary copies from institutions. The library cataloged and classified 1,384 publications; 2,237 periodicals were recorded, and 6,115 catalog cards were filed; 191 cards were sent to the Union Catalogue of the Library of Congress. The library borrowed 945 books on Interlibrary Loan, and the Library of Congress lent 881 books.

The library is the depository for photographs of the works of art in the National Gallery of Art's collections. A stock of reproductions is maintained for use in research, for exchange with other institutions, and for sale to interested individuals. Approximately 5,747 photographs were stocked in the library during the year. The library filled 1,252 orders for photographs. Sales to the general public amounted to \$1,280 covering about 1,982 photographs. There were 288 permits for reproduction of 719 subjects processed in the library.

INDEX OF AMERICAN DESIGN

The work of the Index of American Design during the fiscal year 1960 continued under the direction of Dr. Erwin O. Christensen. Sixteen sets of color slides (793 slides) in 81 bookings were circulated throughout this country and in India. In addition, 79 individual slides were lent for lecture and study purposes. Lecture notes were completed for six slide sets, and 327 photographs of Index material were used for study and publication. The photographic files have been increased by 82 negatives and 903 prints. Approximately 300 visitors used Index material for the purpose of research, publication, and design.

The curator of the Index has continued his participation in the orientation program of USIA personnel.

The photographic file inventory project which was begun last year was completed.

In order to complete the Index, the curator traveled to Indiana to note material in historical societies and museums which may eventually be recorded.

A pamphlet on the 18th century decorative arts in the newly opened Widener rooms was prepared by the department.

The curator published *The History of Western Art* (Volume 1, the New American Library of World Literature). Expert opinions and advisory services were rendered by the curator. Gifts to the Index included a photograph of carved-wood gable figures given by H. F. Kuether, and a "Holly Doll" made and given by Miss Helen Bullard.

MAINTENANCE OF THE BUILDING AND GROUNDS

The Gallery building, the mechanical equipment, and the grounds, have been maintained at the established standards throughout the year, under the direction of Ernest R. Feidler, administrator, and his staff.

The promenade tile on four small roof areas at the East and West Garden Courts was removed and replaced with new copper roofing. The design and installation of the replaced roofing were accomplished by the Gallery maintenance staff.

In keeping with the recommendations of the Committee on the Building and the resolution of the Board of Trustees, in the southwest corner of the ground floor there were completed three new gallery rooms to provide a more suitable background for the French works of art in the Widener Collection and to place on permanent view the Rembrandt drawings in the Widener Collection, which have heretofore been exhibited periodically. One of these rooms is an 18th-century oak-paneled room once in the New York house of Dr. Hamilton Rice. Adjacent to the three new rooms a Graphic Arts area has been constructed and is now being completed. It consists of a Print Exhibition room containing 11 specially designed exhibition cases, a Print Study room, offices for the curator and assistant curator of Graphic Arts, and a print storage room.

LECTOUR

The Gallery's electronic guide system, LecTour, continued to prove its value as an effective tool for art education purposes. It was used by 84,128 visitors during fiscal year 1960, being available in 20 different exhibition areas. Two special exhibitions—one on Daumier's works and one on Japanese Haniwa—received LecTour coverage. The use during fiscal year 1960 represented an increase of more than 15 percent over use in fiscal year 1959.

Flexibility of LecTour lectures was insured by the completion during fiscal year 1960 of a sound studio with the most modern and effective equipment for expeditiously making the Gallery's own recordings and tapes.

OTHER ACTIVITIES

During the fiscal year, 40 Sunday evening concerts were given, 10 of which were given by the National Gallery of Art orchestra directed

by Richard H. Bales. Two of these 10 were made possible by the Music Performance Trust Fund of the American Federation of Musicians. A string orchestra conducted by Mr. Bales furnished music during the opening of the Japanese Haniwa exhibition on January 9, 1960, and at the opening of the new Widener rooms on May 20, 1960. The five Sunday evening concerts in May were devoted to the Gallery's 17th American Music Festival. The Sunday evening concert on October 25, 1959, was dedicated to United Nations Day. All concerts were broadcast in their entirety in stereophonic sound by station WGMS-AM and FM. The Voice of America recorded portions of several Sunday concerts for transmission overseas.

Intermissions during the Sunday concerts featured radio talks by members of the Educational Department and by Mr. Bales.

During the year 12,794 copies of 17 press releases in connection with the Gallery's activities were issued. A total of 166 permits to copy works of art in the Gallery, and 96 photographic permits were issued.

In response to requests 2,862 copies of the pamphlet "A Cordial Invitation from the Director" and 2,582 copies of the Information Booklet were sent to Senators and Representatives for distribution to constituents; and 40,820 copies of the pamphlet "A Cordial Invitation from the Director" and 3,500 copies of the Information Booklet were sent to various organizations holding conventions in Washington.

The slide project begun the last fiscal year was extended, and sets of 500 color slides were placed on permanent deposit with 26 foreign universities and museums. This program was initiated to make the works of art in the National Gallery of Art better known.

A total of 110 publications on the Gallery's collections and exhibitions were sent to various museums in accordance with the Exchange Program.

Henry B. Beville, the Gallery's photographer, and his staff processed 14,567 prints, 193 black-and-white slides, 18,813 color slides, 1,862 black-and-white negatives, 67 color-separation negatives, 393 transparencies, 9 infrared photographs, and 4 ultraviolet photographs, during the fiscal year.

AUDIT OF PRIVATE FUNDS OF THE GALLERY

An audit of the private funds of the Gallery will be made for the fiscal year ended June 30, 1960, by Price Waterhouse & Co., public accountants, and the certificate of that company on its examination of the accounting records maintained for such funds will be forwarded to the Gallery.

Respectfully submitted,

HUNTINGTON CAIRNS, *Secretary.*

Dr. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.



1. Giovanni Battista Montani, Gian Fidenzio, Madauzo, National Gallery of Art, Timken Collection



2. Italian School, XVI century, Mercury, National Gallery of Art Purchase Fund, Andrew W. Mellon Gift



1. Jacob van Ruysdael: Park with a Country House. National Gallery of Art, Gift of Rupert L. Joseph.



2. Tiepolo: Bacchus and Ariadne. National Gallery of Art, Timken Collection



1. Fraconard: The Happy Family. National Gallery of Art, Timken Collection



2 Benjamin West: The Battle of La Hogue. National Gallery of Art Purchase Fund, Andrew W. Mellon Gift.



1. François Boucher: *The Love Letter*. National Gallery of Art, Timken Collection.



2. J. M. W. Turner: *The Evening of the Deluge*. National Gallery of Art, Timken Collection.

Report on the Library

SIR: I have the honor to submit the following report on the activities of the Smithsonian library for the fiscal year ended June 30, 1960:

The library received 72,396 publications during the year, an increase of 19,727 over the preceding year. They came chiefly by exchange from scientific and learned societies located all over the world and written in many languages. These publications are mostly journals in the subject fields of interest to the Institution. New exchanges arranged totaled 168, while special requests for back issues of periodicals numbered 2,363. Purchased publications included 2,750 books and journals which could not be obtained in exchange.

The George H. Clark collection of manuscripts and materials on the history of radio and electronics was the largest single gift received. The transfer of this collection from the Massachusetts Institute of Technology Library was effected by Haraden Pratt of the Institute of Radio Engineers. This gift will be of great value in connection with the Smithsonian's large collection of objects in this field. Other gifts included books and journals from the American Nature Association; 356 items on paleontology from Mrs. J. B. Knight of Alexandria, Va.; another valuable collection of materials on mechanical engineering from Mrs. Carolyn H. Edwards of Glen Echo, Md.; and from the American Association for the Advancement of Science came a large donation of current periodicals. These gifts by generous donors are gratefully acknowledged. In many instances they provide difficult-to-locate source materials.

The original copper plates of the Wilkes Expedition Reports were transferred to the Smithsonian from the Library of Congress. Many of these are believed to be unpublished heretofore and will prove of valuable reference use. Even though written and published over a hundred years ago, these reports continue to be constantly requested.

To the Library of Congress were sent, by transfer, 26,052 publications, many of which were serials and monographs received in exchange; to the National Library of Medicine were sent 1,538 publications; and 516 publications were sent to other Government agencies.

The catalog section cataloged and classified 7,085 books and pamphlets, entered 25,982 periodicals, and filed 33,818 catalog cards. To be an effective key to the library's resources, the card catalog must be

kept up to date. The uncataloged material located in the divisional libraries throughout the Institution hampers effective library service.

The program of discarding obsolete, ephemeral, and duplicate materials continued, with the withdrawal of 11,758 items.

In all, 9,200 volumes of valuable research materials were rebound. In addition, 2,206 items were bound or repaired by the library bindery assistant. New procedures were put into effect which resulted in a speedier and a more efficient handling of the materials to be bound. Other means of preservation, such as microfilming and laminating, will be considered for materials too fragile for commercial binding.

The reference staff answered a total of 30,050 reference and bibliographic questions in response to requests by letter, telephone, or visitors to the library. Visitors numbering 11,565 used the reference and research facilities in the reading rooms. These included, in addition to the Smithsonian staff, local and out-of-town visitors and scientists from other countries. The expanded programs of the Smithsonian have made increased demands on the library staff and its collections. Publications circulated totaled 24,253; 4,792 of these were borrowed from other libraries, chiefly the Library of Congress; 863 volumes were loaned to other libraries.

The branch library which serves the Museum of History and Technology completed a full year of operation. The staff answered 10,670 reference questions, circulated 8,505 publications, and provided service to 3,081 persons who came to the library. The program of binding and rebinding, labeling of books, acquiring of necessary source and reference materials continued in a satisfactory manner. The inventory of the collections progressed slowly because of inadequate catalog records.

There has been an increase in the use of the branch libraries of the Division of Insects and the Bureau of American Ethnology, including use by visiting scholars and other libraries. The stack areas for the Division of Radiation and Organisms and the National Collection of Fine Arts were cleaned and unwanted materials discarded.

New forms used this year and new procedures resulted in greater efficiency in the library service. The most significant improvement was the multiple charge card which has streamlined operations at the circulation desk. A complete review of the old charge file was made, resulting in a more accurate charge-card record. Other means for improvement are being studied, and a continuous review of exchange correspondence files is eliminating unnecessary routines.

The housing of the library is one of the most serious problems. Present facilities for shelving books in the main library are inadequate.

Members of the staff continued their membership in the Special Libraries Association and the American Library Association, several

holding offices in both the local and national organizations. The library was represented at the annual convention of both associations.

Miss Janet S. Dickson, formerly with Pennsylvania State University Library, was appointed chief of the catalog section on October 5, 1959.

SUMMARIZED STATISTICS

ACCESSIONS

	Volumes	Total recorded volumes, 1960
Smithsonian main library (includes former office and museum libraries)-----	2, 887	} 329, 437
Museum of History and Technology-----	2, 626	
Astrophysical Observatory (including Radiation and Organisms)-----	109	15, 187
Bureau of American Ethnology-----	513	38, 262
National Air Museum-----	132	709
National Collection of Fine Arts-----	78	14, 237
National Zoological Park-----	6	4, 293
Total-----	6, 351	402, 125

Unbound volumes of periodicals and reprints and separates from serial publications, of which there are many thousands, have not been included in these totals.

EXCHANGES

New exchanges arranged----- 168
Specially requested publications received----- 2, 363

CATALOGING

Volumes cataloged----- 7, 085
Cataloged cards filed----- 33, 818

PERIODICALS

Periodical parts entered----- 25, 982

CIRCULATION

Loans of books and periodicals----- 24, 253

Circulation in the divisional libraries is not counted except in the Division of Insects.

BINDING AND REPAIR

Volumes sent to the bindery----- 9, 200
Volumes repaired in the library----- 2, 206

Respectfully submitted.

RUTH E. BLANCHARD, *Librarian.*

DR. LEONARD CARMICHAEL,
Secretary, Smithsonian Institution.

Report on Publications

SIR: I have the honor to submit the following report on the publications of the Smithsonian Institution and its branches for the year ended June 30, 1960:

The publications of the Smithsonian Institution are issued partly from federally appropriated funds (Smithsonian Reports and publications of the National Museum, the Bureau of American Ethnology, and the Astrophysical Observatory) and partly from private endowment funds (Smithsonian Miscellaneous Collections, publications of the Freer Gallery of Art, and some special publications). The Institution also edits and publishes under the auspices of the Freer Gallery of Art the series *Ars Orientalis*, which appears under the joint imprint of the University of Michigan and the Smithsonian Institution. The fourth volume in this series was in press at the close of the year. In addition, the Smithsonian publishes a guidebook, a picture pamphlet, postcards and a postcard folder, a color-picture album, color slides, a filmstrip on Smithsonian exhibits, a coloring book for children, and popular publications on scientific and historical subjects related to its important exhibits and collections for sale to visitors. Through its publication program the Smithsonian endeavors to carry out its founder's expressed desire for the diffusion of knowledge.

During the year the Institution published 11 papers and title page and contents to 4 volumes in the Miscellaneous Collections; 1 Annual Report of the Board of Regents and separates of 20 articles in the General Appendix; 1 Annual Report of the Secretary; 1 special publication; and reprints of 3 volumes of Miscellaneous Collections.

The U.S. National Museum issued 1 Annual Report, 4 Bulletins, 20 Proceedings papers and title page, contents, and index for 2 Proceedings volumes and 2 papers in the Series Contributions from the U.S. National Herbarium.

The Bureau of American Ethnology issued 1 Annual Report and 5 Bulletins.

The Astrophysical Observatory issued 8 numbers in the series Smithsonian Contributions to Astrophysics.

The Smithsonian Traveling Exhibition Service, under the National Collection of Fine Arts, published 2 catalogs.

The Freer Gallery of Art issued 1 paper in its Occasional Papers series, 2 catalogs, and volume 3 of *Ars Orientalis*.

DISTRIBUTION

In all, 661,370 copies of publications and miscellaneous items were distributed. *Publications*: 33 Contributions to Knowledge, 31,963 Smithsonian Miscellaneous Collections, 7,373 Annual Report volumes and 23,284 pamphlet copies of Report separates, 44,798 special publications, 233 reports of the Harriman Alaska Expedition, 47,497 publications of the National Museum, 31,547 publications of the Bureau of American Ethnology, 26,671 publications of the National Collection of Fine Arts, 1,112 publications of the Freer Gallery of Art, 16,243 publications of the Astrophysical Observatory, 2,944 Reports of the American Historical Association, and 3,688 publications not issued by the Smithsonian Institution. *Miscellaneous items*: 232 North American Wild Flowers and 6 Wild Flower prints, 4 Pitcher Plant volumes, 48,656 Guide Books, 17,473 picture pamphlets, 255,271 postcards and postcard folders, 20,794 color slides, 78,425 information leaflets, 10 New Museum of History and Technology pamphlets. There were also distributed 401 statuettes, 2,337 Viewmaster reels, and 1 filmstrip and 1 filmstrip record.¹

SMITHSONIAN MISCELLANEOUS COLLECTIONS

In this series, under the immediate editorship of Ruth B. MacManus, there were issued 11 papers and title pages and contents of 4 volumes, as follows:

Volume 119

Title page and table of contents. (Publ. 4384.) [July] 1959.

Volume 135

Title page and table of contents. (Publ. 4386.) [August] 1959.

Volume 136

Title page and table of contents. (Publ. 4387.) [August] 1959.

Volume 138

No. 5. A biological study of Katmai National Monument, by Victor H. Cabalane. 246 pp., 17 pls., 4 figs. (Publ. 4376.) Aug. 20, 1959. (\$3.00.)
Title page and table of contents. (Publ. 4418.) [March] 1960.

Volume 139

No. 2. The birds of Isla Escudo de Veraguas, Panama, by Alexander Wetmore. 27 pp., 1 pl., 3 figs. (Publ. 4378.) July 8, 1959. (50 cents.)
No. 3. Further observations on distribution of patterns of coagulation of the hemolymph in neotropical insects, by Charles Grégoire. 23 pp. (Publ. 4379.) Aug. 18, 1959. (40 cents.)
No. 4. A review of the genus *Hoplomys* (thick-spined rats), with description of a new form from Isla Escudo de Veraguas, Panama, by Charles O. Handley, Jr. 10 pp., 1 fig. (Publ. 4380.) July 3, 1959. (25 cents.)

¹Additional copies of the Institution's filmstrip and record. "Let's Visit the Smithsonian," were distributed through the Society for Visual Education, Chicago, Ill.

- No. 5. Genera of Tertiary and Recent rhynchonellid brachiopods, by G. Arthur Cooper. 90 pp., 22 pls., 1 fig. (Publ. 4382.) Nov. 23, 1959. (\$2.00.)
- No. 6. A revision of the Silurian bryozoan genus *Trematopora*, by Richard S. Boardman. 14 pp., 2 pls., 1 fig. (Publ. 4383.) Oct. 20, 1959. (50 cents.)
- No. 7. Early Tertiary *Apheliscus* and *Phenacodaptes* as pantoletid insectivores, by C. Lewis Gazin. 7 pp., 2 pls. (Publ. 4385.) Aug. 12, 1959. (25 cents.)
- No. 8. The anatomical life of the mosquito, by R. E. Snodgrass. 87 pp., 30 figs. (Publ. 4388.) Nov. 4, 1959. (\$1.00.)
- No. 9. A long-range forecast of United States precipitation, by C. G. Abbot. 78 pp., 12 figs., 9 charts. (Publ. 4390.) Mar. 23, 1960. (\$1.25.)
- No. 11. A classification for the birds of the world, by Alexander Wetmore. 37 pp. (Publ. 4417.) June 23, 1960. (40 cents.)

Volume 140

- No. 1. Classification and multiplicity of growth layers in the branches of trees, by Waldo S. Glock, R. A. Studhalter, and Sharlene R. Agerter. 294 pp., 36 pls., 51 figs. (Publ. 4421.) June 17, 1960. (\$5.00.)

SMITHSONIAN ANNUAL REPORTS

REPORT FOR 1958

The complete volume of the Annual Report of the Board of Regents for 1958 was received from the printer on December 8, 1959:

Annual Report of the Board of Regents of the Smithsonian Institution showing the operations, expenditures, and condition of the Institution for the year ended June 30, 1958. x+559 pp., 92 pls., 15 figs. (Publ. 4354.)

The general appendix contained the following papers (Publ. 4355-4374):

The sun's energy, by Farrington Daniels.

Sun, sea, and air, by Roger Revelle.

Rocketry, by Donald Cox and Michael Stoiko.

Fresh water for arid lands, by David S. Jenkins.

The abundance of the chemical elements, by Hans E. Suess.

Earthquakes and related sources of evidence on the earth's internal structure, by K. E. Bullen.

The Darwin-Wallace centenary, by Sir Gavin de Beer.

Does natural selection continue to operate in modern mankind? by Theodosius Dobzhansky and Gordon Allen.

The ecology of man, by Paul B. Sears.

The sea otter, by Karl W. Kenyon.

Screwworm eradication: concepts and research leading to the sterile-male method, by E. F. Knipling.

Narrative of the 1958 Smithsonian-Bredin Caribbean Expedition, by Waldo L. Schmitt.

Tools make man, by Kenneth Oakley.

The backwash of the frontier: The impact of the Indian on American culture, by A. Irving Hallowell.

The restored Shanidar I skull, by T. D. Stewart.

Acculturation in the Guajira, by Raymond E. Crist.

The Braced-up Cliff at Pueblo Bonito, by Nell M. Judd.

A century of American Indian exhibits in the Smithsonian Institution, by John C. Ewers.

The childhood pattern of genius, by Harold G. McCurdy.

The New England porringer: An index of custom, by Anthony N. B. Garvan.

REPORT FOR 1959

The Report of the Secretary, which will form part of the Annual Report of the Board of Regents to Congress, was issued January 15, 1960:

Report of the Secretary and financial report of the Executive Committee of the Board of Regents for the year ended June 30, 1959. x + 243 pp., 10 pls., 1 map. (Publ. 4389.)

SPECIAL PUBLICATIONS

The Smithsonian Institution. 1959 revised edition. 49 pp., illustr. (Publ. 4145.) [November] 1959.

REPRINTS

Smithsonian Logarithmic Tables, prepared by George Wellington Spenceley, Reba Murray Spenceley, and Eugene Rhodes Epperson. First reprint. Smithsonian Miscellaneous Collections, vol. 118, Publ. 4054. xii + 402 pp. [January] 1960. (\$4.50.)

Smithsonian Physical Tables, prepared by William Elmer Forsythe. Ninth revised edition, second reprint. Smithsonian Miscellaneous Collections, vol. 120, Publ. 4169. vi + 827 pp., 36 figs. [November] 1959. (\$10.00.)

Small arms and ammunition in the United States Service, 1776-1865, by Berkeley R. Lewis. First reprint. Smithsonian Miscellaneous Collections, vol. 129, Publ. 4254. viii + 338 pp., 52 pls., 28 figs. [May] 1960. (\$8.00.)

PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM

The editorial work of the National Museum continued during the year under the immediate direction of John S. Lea, assistant chief of the division. The following publications were issued:

REPORT

The United States National Museum annual report for the year ended June 30, 1959. vi + 178 pp., illustr. Jan. 15, 1960.

BULLETINS

202, vol. 2. Fishes of the Marshall and Marianas Islands, by Leonard P. Schultz and collaborators: Wilbert M. Chapman, Ernest A. Lachner, and Loren P. Woods. ix + 438 pp., pls. 75-123, figs. 91-132. May 11, 1960.

216, part 2. Ichneumon-flies of America north of Mexico: 2. Subfamilies Ephialtinae, Xoridinae, and Acaenitinae, by Henry and Marjorie Townes and collaborators: G. Stuart Walley, Luella Walkley, Dale Habeck, and George Townes. vii + 676 pp., 378 figs. June 24, 1960.

217. Birds of Anaktuvuk Pass, Kobuk, and Old Crow, by Lawrence Irving. viii + 409 pp., 13 pls., 36 figs. Mar. 22, 1960.

218. Contributions from the Museum of History and Technology, Papers 1-11. v + 201 pp., 124 figs. Nov. 16, 1959.

No. 1. The Scholfield wool-carding machines, by Grace L. Rogers.

No. 2. John Deere's steel plow, by Edward C. Kendall.

No. 3. The beginnings of cheap steel, by Philip W. Bishop.

No. 4. The Auburndale Watch Company, by Edwin A. Battison.

No. 5. Development of the phonograph at Alexander Graham Bell's Volta Laboratory, by Leslie J. Newville.

No. 6. On the origin of clockwork, perpetual motion devices, and the compass, by Derek J. de Solla Price.

No. 7. Mine pumping in Agricola's time and later, by Robert P. Multhauf.

No. 8. The natural philosophy of William Gilbert and his predecessors, by W. James King.

No. 9. Conestoga wagons in Braddock's campaign, 1755, by Don H. Berkebile.

No. 10. Old English patent medicines in America, by George B. Griffenhagen and James Harvey Young.

No. 11. Why Bewick succeeded: A note in the history of wood engraving, by Jacob Kainen.

CONTRIBUTIONS FROM THE U.S. NATIONAL HERBARIUM

Volume 35

Part 1. Supplemental notes on the American species of *Passifloraceae* with descriptions of new species, by Ellsworth P. Killip. ii + 23 pp., 11 pls. May 10, 1960.

Volume 36

Part 1. A revision of the South American species of *Parmelia* determined by Lynge, by Mason E. Hale, Jr. 41 pp., 5 pls. May 18, 1960.

PROCEEDINGS

Volume 108

No. 3408. A revision of the butterfly genera *Theochila* and *Tatochila* (Lepidoptera: Pieridae), by José Herrera and William D. Field. Pp. 467-514, 93 figs. July 24, 1959.

Title page, table of contents, and index. Pp. i-v, 599-627. May 11, 1960.

Volume 109

No. 3412. Marine Mollusca of Point Barrow, Alaska, by Nettle MacGinitie. Pp. 59-208, 27 pls. Sept. 18, 1959.

No. 3415. Biting midges of the genus *Culicoides* from Panama (Diptera: Heleidae), by Willis W. Wirth and Franklin S. Blanton. Pp. 237-482, 91 figs. July 29, 1959.

Title page, table of contents, and index. Pp. 1-iii, 483-498. May 18, 1960.

Volume 110

No. 3416. Grasshoppers of the Mexican group, genus *Melanoplus* (Orthoptera: Acrididae), by Ashley B. Gurney and A. R. Brooks. Pp. 1-93, 5 pls., 18 figs. July 9, 1959.

No. 3417. A revision of American bats of the genera *Euderma* and *Plecotus*, by Charles O. Handley, Jr. Pp. 95-246, 27 figs. Sept. 3, 1959.

- No. 3418. A revision of the Apion subgenus *Trichapion* Wagner in the New World (Coleoptera: Curculionidae), by David G. Kissinger. Pp. 247-389, 19 figs. Oct. 23, 1959.
- No. 3419. A description and classification of the final instar larvae of the Ichneumonidae (Insecta, Hymenoptera), by J. R. T. Short. Pp. 391-511, 64 figs. Oct. 23, 1959.
- No. 3420. Mammals of northern Colombia, preliminary report No. 8: Arboreal rice rats, a systematic revision of the subgenus *Oecomys*, genus *Oryzomys*, by Philip Hershkovitz. Pp. 513-563, 12 pls., 6 figs. Feb. 24, 1960.
- No. 3421. The rodent-infesting Anoplura (sucking lice) of Thailand, with remarks on some related species, by Phyllis T. Johnson. Pp. 569-598, 75 figs. Sept. 10, 1959.

Volume 111

- No. 3422. A new American genus of cryptopid centipedes, with an annotated key to the scolopendromorph genera from America north of Mexico, by Ralph E. Crabill, Jr. Pp. 1-15, 16 figs. Jan. 27, 1960.
- No. 3423. A fourth contribution to the knowledge of Neotropical platyrhacid millipeds (Diplopoda: Polydesmida), by Richard L. Hoffman. Pp. 17-31, 1 fig. Feb. 2, 1960.
- No. 3424. Millipeds from Dominica, British West Indies, by Richard L. Hoffman. Pp. 33-41, 2 figs. Jan. 22, 1960.
- No. 3425. Notes on larvae of nine genera of Aphodiinae in the United States (Coleoptera: Scarabaeidae), by Manohar Lal Jerath. Pp. 43-94, 89 figs. Feb. 2, 1960.
- No. 3426. A synopsis of the Atopetholidae, a family of spiroboloid millipeds, by Richard L. Hoffman and Barbara S. Orcutt. Pp. 95-165, 12 figs. Mar. 14, 1960.
- No. 3427. Centipedes of the Smithsonian-Bredin expeditions to the West Indies, by Richard B. Selander and John K. Bouseman. Pp. 197-226, 12 figs. Mar. 14, 1960.

Volume 112

- No. 3432. Flies of the family Conopidae from eastern Asia, by Sidney Camras. Pp. 107-131. June 24, 1960.
- No. 3433. Fireflies of the genus *Pyraclonema* (Coleoptera: Lampyridae), by Frank A. McDermott. Pp. 133-157, 9 figs. June 24, 1960.
- No. 3434. North and South American copepods of the genus *Hemicyclops* (Cyclopoida: Clausidiidae), by Richard U. Gooding. Pp. 159-195, 10 figs. June 17, 1960.
- No. 3435. Chironomid midges of California. I. Chironominae, exclusive of Tanytarsini (=Calopsectrini), by James E. Sublette. Pp. 197-226, 2 figs. June 28, 1960.

PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY

The editorial work of the Bureau continued under the immediate direction of Mrs. Eloise B. Edelen. The following publications were issued:

ANNUAL REPORT

Seventy-sixth Annual Report of the Bureau of American Ethnology, 1958-1959. ii+41 pp., 4 pls. 1960.

BULLETINS

Bulletin 143, Vol. 7. Index to the Handbook of South American Indians. vi+286 pp. 1959.

- Bulletin 172. The story of a Tlingit community: A problem in the relationship between archeological, ethnological, and historical methods, by Frederica de Laguna. x+254 pp., 11 pls., 18 figs. 1960.
- Bulletin 173. Anthropological Papers Nos. 57-62. iii+498 pp., 61 pls., 37 figs., 2 maps. 1960.
- No. 57. Preceramic and ceramic cultural patterns in northwest Virginia, by C. G. Holland.
- No. 58. An introduction to Plains Apache archeology—the Dismal River Aspect, by James H. Gunnerson.
- No. 59. The use of the atlatl on Lake Patzcuaro, Michoacán, by M. W. Stirling.
- No. 60. A Caroline Islands script, by Saul H. Rosenberg and Shigeru Kaneshiro.
- No. 61. Dakota winter counts as a source of Plains history, by James H. Howard.
- No. 62. Stone tipi rings in north-central Montana and the adjacent portion of Alberta, Canada: Their historical, ethnological, and archeological aspects, by Thomas F. Kehoe.
- Bulletin 174. An introduction to Kansas archeology, by Waldo R. Wedel. With description of the skeletal remains from Doniphan and Scott Counties, Kansas, by T. D. Stewart. xvii+723 pp., 97 pls., 109 figs. 1959.
- Bulletin 177. Archeological investigations in British Guiana, by Clifford Evans and Betty J. Meggers. xxi+418 pp., 68 pls., 127 figs. 1960.

PUBLICATIONS OF THE ASTROPHYSICAL OBSERVATORY

The editorial work of the Smithsonian Astrophysical Observatory continued under the immediate direction of Ernest E. Biebighauser. The year's publications are as follows:

Volume 3

- No. 6. A fluid-dynamic mechanism of meteorite pitting, by David T. Williams. Pp. 47-67, 14 pls., 9 figs. 1959.
- No. 7. Periodic orbits of a planetoid passing close to two gravitating masses, by Robert R. Newton. Pp. 69-78, 5 figs. 1959.
- No. 8. Meteor trains, by Robert F. Hughes. Pp. 79-94, 13 figs. 1959.
- No. 9. Geodetic uses of artificial satellites, by George Vels. Pp. i-iv, 95-161, 23 figs. 1960.

Volume 4

- No. 1. Catalog of hourly meteor rates, by Charles P. Olivier. Pp. 1-14. 1960.

Volume 5

- No. 1. The meteoric head echo, by Allen F. Cook and Gerald Hawkins. Pp. 1-7, 2 figs. 1960.
- No. 2. The upper atmosphere and satellite drag, by R. J. Stirton. Pp. 9-15, 5 figs. 1960.
- No. 3. On the structure of the sunspot zone, by Barbara Bell. Pp. 17-28, 15 figs. 1960.

PUBLICATIONS OF THE NATIONAL COLLECTION OF FINE ARTS

- The art of Seth Eastman, by John Francis McDermott. Smithsonian Traveling Exhibition Service Catalog. 34 pp., 9 plate figs. 1959.
- Smithsonian Institution Traveling Exhibitions, 1960-1961 catalog. 40 pp. 1960.

PUBLICATIONS OF THE FREER GALLERY OF ART

- Calligraphers and painters: A treatise by Qadi Ahmad, son of Mir-Munshi (circa A.H. 1015/A.D. 1606). Translated from the Persian by V. Minorsky. With an introduction by B. N. Zakhoder, translated from the Russian by T. Minorsky. Freer Gallery of Art Occ. Pap., vol. 3, No. 2. x+225 pp., 8 pls. (Publ. 4339.) 1959. (\$4.00.)
- Hokusai paintings and drawings in the Freer Gallery of Art, by Harold P. Stern. Catalog. 40 pp., 36 pls. (Publ. 4419). 1960. (\$1.00.)
- Medieval Near Eastern ceramics in the Freer Gallery of Art, by Richard Ettinghausen. Catalog. 40 pp., 40 plate figs. (Publ. 4420.) 1960. (\$1.00.)
- Ars Orientalis, vol. 3. vi+263 pp., 132 pls., 28 figs. (Publ. 4381.) 1959. (\$20.00.)

REPORTS OF THE AMERICAN HISTORICAL ASSOCIATION

The annual reports of the American Historical Association are transmitted by the Association to the Secretary of the Smithsonian Institution and are by him communicated to Congress, as provided in the act of incorporation of the Association. The following reports were issued during the year:

- Annual Report of the American Historical Association, 1955. Vol. 2, Writings on American History, 1953. 1960.
- Annual Report of the American Historical Association, 1958. Vol. 1, Proceedings. 1959.

REPORT OF THE NATIONAL SOCIETY, DAUGHTERS OF THE AMERICAN REVOLUTION

In accordance with law, the manuscripts of the sixty-first and sixty-second annual reports of the National Society, Daughters of the American Revolution, were transmitted to Congress on February 1 and March 7, 1960, respectively.

OTHER ACTIVITIES

During the year the Smithsonian Institution was elected to affiliate membership in the Association of American University Presses. Late in May, the chief of the Editorial and Publications Division attended the annual meeting of the Association in Pittsburgh, representing the Institution and formally accepting the membership.

A project consummated during the year was the editing of "Smithsonian Treasury of Science," an anthology of 50 articles that have appeared over the years in the General Appendices of the Report of the Board of Regents of the Smithsonian. These appendices, which have appeared in the Report without a break for well over a century, have contained many outstanding and important articles in science and technology, most of them by eminent scientists and writers. Written primarily for the general public, rather than for specialized readers, they have formed a significant part of the Institution's pro-

gram for the diffusion of knowledge. It was felt that bringing the best of the articles together for a wider readership would be well worthwhile from many standpoints. The new work, edited by W. P. True, former chief of the division, will appear in a 3-volume set in the fall of 1960, published by Simon & Schuster, Inc., of New York, in cooperation with the Smithsonian.

The chief of the division continued to represent the Smithsonian Institution on the board of directors of the Greater Washington Educational Television Association, Inc., of which the Institution is a member.

Respectfully submitted.

PAUL H. OEHSER,

Chief, Editorial and Publications Division.

DR. LEONARD CARMICHAEL,

Secretary, Smithsonian Institution.

Other Activities

LECTURES

In 1931 the Institution received a bequest from James Arthur, of New York City, a part of the income from which was to be used to endow an annual lecture on some aspect of the sun. The 26th Arthur lecture was delivered in the auditorium of the Natural History Building on the evening of October 15, 1959, by Dr. Alan Maxwell, research associate of the Radio Astronomy Station of Harvard College Observatory, Fort Davis, Tex., on the subject "Radio Waves from the Sun." This lecture, the first in the series that has been concerned with radio astronomy, was published in full in the general appendix of the Annual Report of the Board of Regents of the Smithsonian Institution for 1959.

Dr. George E. Mylonas, professor and chairman of the Department of Art and Archaeology of Washington University, St. Louis, Mo., delivered a lecture on "Eleusis, Its Sanctuary and Cemetery" in the auditorium of the Natural History Building on the evening of February 25, 1960. This was sponsored jointly by the Smithsonian and the Archaeological Institute of America.

Several lectures were also sponsored by the Freer Gallery of Art and the National Gallery of Art. These are listed in the reports of these bureaus.

Many other lectures on technical subjects were given at the Smithsonian during the year.

BIO-SCIENCES INFORMATION EXCHANGE

The Bio-Sciences Information Exchange, an agency operated within the Smithsonian Institution but financed by other Government agencies, is a clearing house for research in the life sciences.

Abstracts of on-going research are registered by investigators engaged in biological, medical, and psychological research and in limited aspects of research in the social sciences. Through an extensive system of subject indexing, these abstracts are provided upon request and without charge to researchers in research institutions. Through this simple mechanism, the Exchange maintains a communication system which precedes publication and prevents unknowing duplication. For granting agencies and properly constituted committees it prepares extensive surveys of research in broad areas.

The efficiency of the Bio-Sciences Information Exchange is greatly aided by the functional arrangement of its new offices and its electronic equipment. A Burroughs 205 computer was installed in October and considerable progress has been made toward conversion to operation on magnetic tape.

The volume of information in the Bio-Sciences Information Exchange continues to grow; approximately 30,000 current research studies are presently registered. The services of the Exchange are used increasingly by the scientific public as well as by granting agencies. The National Aeronautics and Space Administration joined the other Federal agencies supporting the Exchange this year.

One new professional, Willis Foster, M.D., joined the staff in July.

Conversations among Federal agencies are in progress concerning broadening the scope of the Exchange to include the physical as well as the biological sciences.

SMITHSONIAN MUSEUM SERVICE

The Smithsonian Museum Service, through appropriate educational media, interprets to museum visitors and to the general public, the objects, specimens, and exhibits of the several Smithsonian museums and develops educational programs for interpreting the work of the Institution in the fields of science, natural history, art, and history. The activity of the Museum Service includes the administration of Smithsonian cooperation with the volunteer docents of the Junior League of Washington, D.C. A more complete report of this activity is carried in the Report of the United States National Museum.

The Museum Service also provided assistance to professional and subprofessional individuals and groups visiting the museums of the Institution. Arrangements were made through the Museum Service for Smithsonian participation in the Workshop on the Use of Community Resources sponsored by the University of Maryland. Through the facilities of this workshop, a 5-day program outlining the history of the Institution and the work of the various Smithsonian museum and research bureaus was presented to 39 graduate students from the University of Maryland. Assistance in the form of lectures, answers to inquiries, and special tours of certain museum areas was also rendered to other college and university groups visiting the Institution and to individuals from the United States and abroad, visiting, or planning to visit the Smithsonian in a professional capacity.

The Museum Service took the first step in a long-range project to orient visitors to the various museums and exhibits of the Institution, through the installation and operation of an electronically controlled, automatic slide lecture device in the Great Hall of the Smithsonian Building.

Arrangements for various Smithsonian public functions and events, including lectures, films, and the opening of new halls and exhibits were made by the Museum Service. More complete information about these activities will be found under appropriate headings elsewhere in the Annual Report of the Secretary of the Smithsonian Institution. Mailing lists for invitations to these functions were enlarged and maintained, and the Smithsonian *Calendar of Events*, a monthly listing of special events of the Institution was prepared and distributed.

Report of the Executive Committee of the Board of Regents of the Smithsonian In- stitution

For the Year Ended June 30, 1960

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds of the Smithsonian Institution, together with a statement of the appropriations by Congress for the Government bureaus in the administrative charge of the Institution.

SMITHSONIAN INSTITUTION

PARENT FUND

The original bequest of James Smithson was £104,960 8s 6d—\$508,318.46. Refunds of money expended in prosecution of the claim, freight, insurance, and other incidental expenses, together with payment into the fund of the sum of £5,015, which had been withheld during the lifetime of Madame de la Batut, brought the fund to the amount of \$550,000.

The gift of James Smithson was "lent to the United States Treasury, at 6 per centum per annum interest" (20 USC. 54) and by the Act of March 12, 1894 (20 USC. 55) the Secretary of the Treasury was "authorized to receive into the Treasury, on the same terms as the original bequest of James Smithson, such sums as the Regents may, from time to time see fit to deposit, not exceeding, with the original bequest the sum of \$1,000,000."

The maximum of \$1,000,000 which the Smithsonian Institution was authorized to deposit in the Treasury of the United States was reached on January 11, 1917, by the deposit of \$2,000.

Under the above authority the amounts shown below are deposited in the United States Treasury and draw 6 percent interest:

	<i>Unrestricted funds</i>	<i>Income 1960</i>
James Smithson.....	\$727, 640	\$43, 658. 40
Avery.....	14, 000	840. 00
Habel.....	500	30. 00
Hamilton.....	2, 500	150. 00
Hodgkins (general).....	116, 000	6, 960. 00
Poore.....	26, 670	1, 600. 20
Rhees.....	590	35. 40
Sanford.....	1, 100	66. 00
Total	889, 000	53, 340. 00
	<i>Restricted funds</i>	
Hodgkins (specific).....	100, 000	6, 000. 00
Reid.....	11, 000	660. 00
Total	111, 000	6, 660. 00
Grand total	\$1, 000, 000	\$60, 000. 00

In addition to the \$1,000,000 deposited in the Treasury of the United States there has been accumulated from income and bequests the sum of \$3,716,789.35 which has been invested. Of this sum, \$3,607,281.51 is carried on the books of the Institution as the Consolidated Fund, a policy approved by the Regents at their meeting on December 14, 1916. The balance is made up of several small funds.

CONSOLIDATED FUND

(Income for the unrestricted use of the Institution)

Fund	Investment 1960	Income 1960
Abbott, W. L., Special.....	\$20, 726. 76	\$1, 107. 19
*Avery, Robert S. and Lydia.....	54, 951. 79	2, 936. 06
Gifts, royalties, gain on sale of securities.....	384, 126. 43	20, 523. 76
Hachenberg, George P. and Caroline.....	5, 595. 10	298. 96
*Hamilton, James.....	561. 59	30. 01
Hart, Gustavus E.....	677. 62	36. 18
Henry, Caroline.....	1, 682. 55	89. 92
Henry, Joseph and Harriet A.....	68, 197. 81	3, 643. 79
*Hodgkins, Thomas G. (general).....	42, 143. 05	2, 251. 68
Morrow, Dwight W.....	107, 580. 49	5, 747. 97
Olmsted, Helen A.....	1, 115. 36	59. 53
*Poore, Lucy T. and George W.....	226, 424. 24	12, 096. 78
Porter, Henry Kirke.....	398, 433. 63	21, 288. 21
*Rhees, William Jones.....	658. 20	35. 15
*Sanford, George H.....	1, 238. 44	66. 19
*Smithson, James.....	1, 698. 42	90. 73
Witherspoon, Thomas A.....	179, 535. 92	9, 591. 53
Total	1, 495, 347. 40	79, 893. 64

*In addition to funds deposited in the United States Treasury.

CONSOLIDATED FUND

(Income restricted to specific use)

Fund	Investment 1960	Income 1960
Abbott, William L., for investigations in biology	\$145,242.68	\$7,701.61
Arthur, James, for investigations and study of the sun and annual lecture on same	55,639.21	2,972.79
Bacon, Virginia Purdy, for traveling scholarship to investigate fauna of countries other than the United States	69,700.74	3,724.07
Baird, Lucy H., for creating a memorial to Secretary Baird	33,496.00	1,789.66
Barney, Alice Pike, for collection of paintings and pastels and for encouragement of American artistic endeavor	39,902.20	2,131.96
Barstow, Frederick D., for purchase of animals for National Zoological Park	1,390.87	74.32
Canfield Collection, for increase and care of the Canfield collection of minerals	53,209.73	2,843.00
Casey, Thomas L., for maintenance of the Casey collection and promotion of researches relating to Coleoptera	17,438.11	931.72
Chamberlain, Francis Lea, for increase and promotion of Isaac Lea collection of gems and mollusks	39,177.19	2,093.23
Dykes, Charles, for support in financial research	59,902.53	3,200.25
Eickemeyer, Florence Brevoort, for preservation and exhibition of the photographic collection of Rudolph Eickemeyer, Jr.	15,121.68	807.94
Hanson, Martin Gustav and Caroline Runice, for some scientific work of the Institution, preferably in chemistry or medicine	12,367.69	660.81
Hillyer, Virgil, for increase and care of Virgil Hillyer collection of lighting objects	9,143.28	488.50
Hitchcock, Albert S., for care of the Hitchcock Agrostological Library	2,195.26	117.27
Hrdlička, Aleš and Marie, to further researches in physical anthropology and publication in connection therewith	63,291.13	3,210.11
Hughes, Bruce, to found Hughes alcove	26,629.65	1,422.82
Loeb, Morris, for furtherance of knowledge in the exact sciences	121,247.99	6,477.24
Long, Annette and Edith C., for upkeep and preservation of Long collection of embroideries, laces, and textiles	755.39	40.35
Maxwell, Mary E., for care and exhibition of Maxwell collection	27,287.52	1,456.98
Myer, Catherine Walden, for purchase of first-class works of art for use and benefit of the National Collection of Fine Arts	28,101.09	1,501.42
Nelson, Edward W., for support of biological studies	30,938.64	1,653.05

CONSOLIDATED FUND—Continued

Fund	Investment 1960	Income 1960
Noyes, Frank B., for use in connection with the collection of dolls placed in the U.S. National Museum through the interest of Mr. and Mrs. Noyes.....	\$1, 336. 59	\$71. 39
Pell, Cornelia Livingston, for maintenance of Alfred Duane Pell collection.....	10, 312. 28	550. 96
Petrocelli, Joseph, for the care of the Petrocelli collection of photographic prints and for the enlargement and development of the section of photography of the U.S. National Museum.....	10, 313. 21	551. 01
Rathbun, Richard, for use of division of U.S. National Museum containing Crustacea.....	14, 796. 89	790. 61
Reid, Addison T., ¹ for founding chair in biology, in memory of Asher Tunis.....	24, 745. 63	1, 081. 72
Roebbling Collection, for care, improvement, and increase of Roebbling Collection of minerals.....	167, 902. 74	8, 969. 98
Roebbling Solar Research.....	32, 072. 20	1, 713. 61
Rollins, Miriam and William, for investigations in physics and chemistry.....	188, 051. 15	9, 785. 13
Smithsonian employees' retirement.....	33, 221. 51	1, 807. 54
Springer, Frank, for care and increase of the Springer collection and library.....	24, 948. 37	1, 331. 96
Strong, Julia D., for benefit of the National Collection of Fine Arts.....	13, 909. 98	743. 21
Walcott, Charles D. and Mary Vaux, for development of geological and paleontological studies and publishing results of same.....	667, 140. 38	35, 503. 44
Walcott, Mary Vaux, for publications in botany.....	80, 530. 58	4, 302. 72
Younger, Helen Walcott, held in trust.....	97, 112. 27	5, 188. 04
Zerbee, Frances Brinckle, for endowment of aquaria.....	1, 319. 65	70. 52
Total.....	2, 219, 892. 01	117, 760. 94

¹ In addition to funds deposited in the United States Treasury.

FREER GALLERY OF ART FUND

Early in 1906, by deed of gift, Charles L. Freer, of Detroit, gave to the Institution his collection of Chinese and other Oriental objects of art, as well as paintings, etchings, and other works of art by Whistler, Thayer, Dewing, and other artists. Later he also gave funds for construction of a building to house the collection, and finally in his will, probated November 6, 1919, he provided stocks and securities to the estimated value of \$1,958,591.42, as an endowment fund for the operation of the Gallery. The fund now amounts to \$9,054,863.05.

SUMMARY OF ENDOWMENTS

Invested endowment for general purposes.....	\$2, 384, 347. 40
Invested endowment for specific purposes other than Freer endowment.....	2, 332, 441. 95
Total invested endowment other than Freer.....	4, 716, 789. 35
Freer invested endowment for specific purposes.....	9, 054, 863. 05
Total invested endowment for all purposes.....	13, 771, 652. 40

CLASSIFICATION OF INVESTMENTS

Deposited in the U.S Treasury at 6 percent per annum, as authorized in the U.S. Revised Statutes, sec. 5591.....	1, 000, 000. 00
Investments other than Freer endowment (cost or market value at date acquired):	
Bonds.....	\$1, 435, 639. 64
Stocks.....	2, 267, 442. 96
Real estate and mortgages.....	701. 00
Uninvested capital.....	13, 005. 75
Total investments other than Freer endowment.....	4, 716, 789. 35
Investments of Freer endowment (cost or market value at date acquired):	
Bonds.....	\$5, 055, 066. 30
Stocks.....	3, 971, 028. 11
Uninvested capital.....	28, 768. 64
Total investments.....	13, 771, 652. 40

ASSETS

Cash:	
United States Treasury current account.....	\$1, 276, 049. 62
In banks and on hand..	511, 002. 19
	1, 787, 051. 81
Less uninvested endowment funds.....	41, 774. 39
	\$1, 745, 277. 42
Travel and other advances.....	7, 785. 20
Cash invested (U.S. Treasury notes).....	1, 328, 878. 18
	3, 081, 940. 80
Investments—at book value:	
Endowment funds:	
Freer Gallery of Art:	
Stocks and bonds....	\$9, 026, 094. 41
Uninvested cash.....	28, 768. 64
	9, 054, 863. 05

ASSETS—Continued

Investments at book value other than

Freer:

Stocks and bonds (Consolidated Fund)----	\$3, 603, 299. 33	
Uninvested cash-----	13, 005, 75	
Special deposit in U.S. Treasury at 6 percent interest--	1, 000, 000. 00	
Other stocks and bonds-----	99, 783. 27	
Real estate and mortgages-----	701. 00	
	<u>\$4, 716, 789. 35</u>	\$13, 771, 652. 40
Total-----		<u>16, 853, 593. 20</u>

UNEXPENDED FUNDS AND ENDOWMENTS

Unexpended funds:

Income from Freer Gallery of Art endowment-----		\$625, 788. 70
Income from other endowments:		
Restricted-----	\$501, 326. 58	
General-----	623, 034. 11	
	<u></u>	1, 124, 360. 69
Gifts and contributions-----		<u>1, 331, 791. 41</u>

3, 081, 940. 80

Endowment funds:

Freer Gallery of Art-----	\$9, 054, 863. 05	
Other:		
General-----	2, 384, 347. 40	
Restricted-----	2, 332, 441. 95	
	<u></u>	13, 771, 652. 40
Total-----		<u>16, 853, 593. 20</u>

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING FISCAL YEAR 1960¹

	Restricted funds		Unrestricted funds	Gifts and grants	Total
	General	Freer			
RECEIPTS:					
Income from investments:					
Freer fund.....		\$438,820.08			\$438,820.08
Consolidated fund.....	\$105,188.51		\$79,893.64		185,082.15
Loan to U.S. Treasury.....	6,660.00		53,340.00		60,000.00
Real estate and mortgages.....	222.31				222.31
Special funds—stocks and bonds.....	5,456.54		39,633.75		45,090.29
Total income from investments.....	117,527.36	438,820.08	172,867.39		729,214.83
Publications.....	1,848.27	12,972.38	97,468.31	\$10,990.08	123,279.04
Research grant income.....			51,796.77		51,796.77
Special gifts and fees:					
Gifts and contributions.....	1,623.67		2,555.00	24,157,748.15	4,161,926.82
Special service fees.....	1,470.45	575.75	12,502.91	179,257.67	193,806.68
Refund of advances (net).....			(3,358.43)		(3,358.43)
Employees' withholdings (net).....			30,290.11		30,290.11
Total special gifts and fees.....	3,094.12	575.75	41,959.59	4,337,005.72	4,382,665.18
Reinvestment (required by provision of donor).....	8,754.83				8,754.83
Total income.....	131,224.58	452,368.21	364,122.06	4,347,995.80	5,295,710.65
Sales of securities:					
Endowment funds:					
Freer fund.....		381,387.86			381,387.86
Consolidated fund.....	96,026.43		68,149.37		164,175.80
Total sales of securities.....	96,026.43	381,387.86	68,149.37		545,563.66
Redemption of mortgages.....	5,055.00				5,055.00
Total receipts.....	232,306.01	833,756.07	432,271.43	4,347,995.80	5,846,329.31
DISBURSEMENTS:					
Administrative salaries.....		36,898.36	95,593.05		132,491.41
Other salaries.....	10,639.61	151,177.41			161,808.02
Total salaries.....	10,639.61	188,075.77	95,593.05		294,299.43
Purchases for collection.....	11,045.75	123,952.09			134,997.75
Research and explorations and related administrative expenses:					
Salaries ¹			23,449.43	1,739,730.72	1,763,189.15
Travel.....	9,691.21	5,800.93	3,320.88		18,813.02
Equipment and supply.....	1,328.01		1,963.03		3,291.04
Other ²	3,192.66		7,293.50	2,760,531.82	2,771,017.98
Total research and exploration and related administrative expense.....	14,211.88	5,800.93	36,026.84	4,500,271.54	4,556,311.19

¹ This statement does not include Government appropriations under administrative charge of the Institution.

² Includes receipts for IGY program.

³ Includes disbursements for IGY program.

CASH BALANCES, RECEIPTS, AND DISBURSEMENTS DURING FISCAL YEAR 1960 ¹—Continued

	Restricted funds		Unrestricted funds	Gifts and grants	Total
	General	Freer			
DISBURSEMENTS—Continued					
Publications.....	\$10,255.19	\$28,168.50	\$65,427.50		\$103,851.19
Buildings, equipment, and grounds:					
Buildings and installations.....		12,680.68	1,038.35		13,719.03
Court and grounds maintenance.....		447.11			447.11
Technical laboratory.....		838.57			838.57
Total buildings, equipment and grounds.....		13,966.36	1,038.35		15,004.71
Contractual services:					
Custodian and legal fees.....	7,509.75	11,618.29	4,758.68		23,886.73
Supplies and expenses:					
Meetings, special exhibits.....		13,151.94	5,841.10		18,993.04
Lectures.....	593.00	1,788.26			2,381.26
Photographs and reproductions.....		5,593.27	445.56		6,038.83
Library.....		3,123.06	1,140.01		4,263.07
Stationery and office supplies.....			160.05		160.05
Postage, telephone, and telegraph.....			881.08		881.08
Stamp machines.....			405.50		405.50
Total supplies and expenses.....	593.00	23,656.53	8,873.30		33,122.83
Total expenses.....	54,216.19	395,238.38	211,717.72	\$4,500,271.54	5,161,473.83
Purchases of securities:					
Endowment funds:					
Freer fund.....		354,670.74			354,670.74
Consolidated fund.....	102,318.11		72,635.86		174,954.00
Other stocks and bonds.....	10.84				10.84
Total endowment funds.....	102,338.95	354,670.74	72,635.86		529,645.55
Total disbursements.....	156,605.17	749,909.12	284,353.58	4,500,271.54	5,691,139.41
Excess receipts over disbursements.....	75,700.54	\$3,546.95	147,917.85	(152,275.74)	155,189.90
Cash balance June 30, 1959.....					1,631,861.91
Cash balance June 30, 1960.....					1,787,051.81

The practice of maintaining savings accounts in several of the Washington banks and trust companies has been continued during the past year, and interest on these deposits amounted to \$6,304.73.

Deposits are made in banks for convenience in collection of checks, and later such funds are withdrawn and deposited in the United States Treasury. Disbursement of funds is made by check signed by the Secretary of the Institution and drawn on the United States Treasury.

The Institution gratefully acknowledges gifts and grants from the following:

- American Institute of Biological Sciences, to defray travel of Dr. Ernest A. Lachner.
- American Institute of Biological Sciences, to assist in publishing a manuscript on "The Biotic Associations of Cockroaches," by Drs. Louis M. Roth and Edwin R. Willis.
- American Philosophical Society, to be used in connection with Dr. Wallace L. Chafe's Indian language studies.
- American Philosophical Society, to assist in defraying expenses of Dr. William C. Sturtevant while attending the Sixth International Congress of Anthropological and Ethnological Sciences, held in Paris, France.
- American Philosophical Society, for the study of Comparative Collections of Northern South American materials in European Museums by Drs. Clifford Evans and Betty J. Meggers.
- American Philosophical Society, to defray expenses of Dr. Henry B. Collins while attending the International Anthropological Congress, Paris, France.
- Mrs. Jessie W. Armstrong, to the Smithsonian Institution to establish fund to be known as the "Edwin James Armstrong Fund" for use of the Department of Invertebrate Paleontology.
- Atomic Energy Commission, grant for support of research entitled "Systematic Zoological Research on the Marine Fauna of the Tropical Pacific Area."
- Atomic Energy Commission, for support of research and study of the Biochemical Effects of Ionizing and Nonionizing Radiation on Plant Metabolism during development.
- Mr. J. Bruce Bredin, additional gift for the Smithsonian-Bredin Expeditions Fund.
- Columbia University, grant to defray expenses of Dr. T. Dale Stewart to Baghdad and return, in connection with his work for the Smithsonian Institution.
- F. E. Compton Company, grant for support in Improvement of the National Air Museum Library.
- Department of Air Force, for research entitled "Study of Atmospheric Entry and Impact of High Velocity Meteorites."
- Department of Air Force, additional grant for support of research and planning in connection with manned and unmanned balloon flights.
- Department of Air Force, additional grant for support of research entitled "The Accretion of Meteorite Material by the Earth."
- Department of Air Force, additional grant in support of research entitled "Scintillation Data on Balloon-Borne Telescope."
- Department of Army, Ordnance Corps, additional grant for research entitled "Procurement of Satellite Tracking and Orbit."
- Department of Health, Education, and Welfare, for support of research entitled "Economic System of the Herrero."
- Entomological Society of America, to assist in defraying the expenses of Dr. J. F. G. Clarke to Europe in connection with his work for the Smithsonian Institution.
- General Dynamics Corporation for the Meteorite Fund.
- Guggenheim Memorial Foundation, Fellowship grant for Dr. Ernest A. Lachner.
- Mr. E. P. Henderson, gift for the Meteorite Fund.
- International Business Machines, gift for the purchase of a collection of antique instruments.
- Jersey Production Research Corporation, additional grant for support of research project on Echinoid Spines.
- Mr. E. A. Link, gift for support of the Marine Biological Project.

- Link Foundation, gift for support of special publications dealing with aviation and the Smithsonian Institution Collections.
- Michigan Mineralogical Society, gift to defray travel expenses of Dr. George S. Switzer to attend the annual meeting of the Michigan Mineralogical Society.
- National Aeronautics and Space Administration, grants for support of the Satellite Tracking Program; astronomical telescope studies.
- National Aeronautics and Space Administration and the National Science Foundation, grant for the "Acquisition of the Beyer Tektite Collection."
- National Aviation Club, grant for the purpose of purchasing the C. G. B. Stuart Aviation Book Collection.
- National Geographic Society, grant to help defray expenses in connection with the underwater archeological expedition to Port Royal, Jamaica, under the auspices of the National Geographic Society-Smithsonian Institution.
- National Geographic Society, additional grant for the continuation of a joint study by the National Geographic Society and Smithsonian Institution on the boatzoin.
- National Geographic Society, additional grant to cover the preparation of technical drawings of fishes for illustration in the report on the collection of fishes made during the Arnhem Land Expedition.
- National Science Foundation, for support of research entitled "Early Tertiary Mammals of North America."
- National Science Foundation, for the support of research entitled "A Monograph of the Lichen Genus *Parmelia*."
- National Science Foundation, grant for the support of research entitled "Behavior Patterns of Certain Tropical American Carnivores."
- National Science Foundation, additional grant for support of research entitled "Metabolic Aspects of the Digestion of Wax."
- National Science Foundation, additional grant for support of research entitled "A Monograph of Fresh-Water Calanoid Copepoda."
- National Science Foundation, grant to assist in defraying expenses of Dr. William C. Sturtevant while attending the Sixth International Congress of Anthropological and Ethnological Sciences held in Paris, France.
- National Science Foundation, grant for support of research entitled "The Flora of Fiji"; for research entitled "Economic System of the Herrero."
- National Science Foundation, grant for support of research entitled "Mammals of the Southeastern United States."
- National Science Foundation, grant for partial support of publication for "Classification and Multiplicity of Growth Layers in the Branches of Trees" by Glock, Studhalter, and Agarter.
- National Science Foundation, grant to assist in defraying expenses of travel of Dr. George S. Switzer to Zurich, Switzerland for the purpose of attending the meeting of the International Mineralogical Association.
- National Science Foundation, additional grant for the support of research entitled "Morphology and Paleocology of Permian Brachiopods."
- National Science Foundation, additional grant for the support of research entitled "Comparative Analysis of Behavior in Tropical Birds."
- National Science Foundation, additional grant for the support of research entitled "Taxonomy of the Bamboos."
- National Science Foundation, additional grant for the support of research entitled "Monograph of the Cassiduloidea"; support of research entitled "Studies of World-Wide Fungus Order Ustilaginales."
- National Science Foundation, additional grant for research entitled "A Taxonomic Study of the Phanerogams of Colombia."

National Science Foundation, grant for the support of research entitled "Systematics of Chilopoda and Diplopoda."

National Science Foundation, grant supporting research entitled "Revisionary Study of Blattoides."

New York Mineralogical Club, grant to defray expenses of Mr. Paul E. Desautels from Washington, D. C., to New York City and return.

Office of Naval Research, additional grants to perform aeronautical research studies ; to perform psychological research studies.

Office of Naval Research, additional grant for study concerning the development of a proposal for an institute or laboratory of human performance standards.

Office of Naval Research, additional grant for support of research in connection with studies on the marine fauna of the South Pacific Ocean.

Office of Naval Research, additional grants to provide expert consultants to advise the Navy Advisory Committee.

Office of Naval Research, additional grant for support of research entitled "Information on Shark Distribution and the Distribution of Shark Attacks All Over the World."

Rochester Academy of Sciences, for the use of Mr. Paul E. Desautels in connection with his work for the Smithsonian Institution.

St. Petersburg Shell Club, grant to defray expenses of Dr. Harald Rehder to and from St. Petersburg, Florida.

School of Science of the Venezuela Central University, grant for the purpose of purchasing equipment to be used in conducting field work on mammals in Venezuela by Dr. Charles O. Handley, Jr.

Mrs. L. Corrin Strong, gift to the Smithsonian Institution Traveling Exhibition Service for the purpose of exhibiting "Norwegian Tapestries" at the Smithsonian Institution.

Mr. Ganson Taggart, bequest to the Smithsonian Institution.

Woods Hole Oceanographic Institution, grant to defray expenses of Dr. Richard Cifelli on an expedition to the West Indies.

For support of the Bio-Sciences Information Exchange:

Atomic Energy Commission.
Department of the Air Force.
Department of the Army.
Department of Defense.
Department of the Navy.
National Science Foundation.
Public Health Service.
Veterans Administration.

Included in the above list of gifts and contributions are reimbursable contracts.

The foregoing report relates only to the private funds of the Institution.

The following appropriations were made by Congress for the Government bureaus under the administrative charge of the Smithsonian Institution for the fiscal year 1960:

Salaries and expenses.....	\$7, 718, 000. 00
National Zoological Park.....	1, 165, 200. 00

The appropriation made to the National Gallery of Art (which is a bureau of the Smithsonian Institution) was \$1,834,000.00.

In addition, funds were transferred from other Government agencies for expenditure under the direction of the Smithsonian Institution as follows:

Working Funds, transferred from the National Park Service, Interior Department, for archeological investigations in river basins throughout the United States----- \$122,055.00

The Institution also administers a trust fund for partial support of the Canal Zone Biological Area, located on Barro Colorado Island in the Canal Zone.

AUDIT

The report of the audit of the Smithsonian Private Funds follows:

WASHINGTON, D.C., September 26, 1960.

THE BOARD OF REGENTS,

Smithsonian Institution, Washington 25, D.C.

We have examined the statement of private funds of Smithsonian Institution as of June 30, 1960 and the related statement of private funds cash receipts and disbursements for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

Land, buildings, furniture, equipment, works of art, living and other specimens and certain sundry property are not included in the accounts of the Institution; likewise, the accompanying statements do not include the National Gallery of Art and other departments, bureaus and operations administered by the Institution under Federal appropriations. The accounts of the Institution are maintained on the basis of cash receipts and disbursements, with the result that the accompanying statements do not reflect income earned but not collected or expenses incurred but not paid.

In our opinion, subject to the matters referred to in the preceding paragraph, the accompanying statement of private funds present fairly the assets, unexpended funds and endowments of the private funds of Smithsonian Institution at June 30, 1960; further, the accompanying statement of private funds cash receipts and disbursements, which has been prepared on a basis consistent with that of the preceding year, presents fairly the cash transactions of the private funds for the year then ended.

PEAT, MARWICK, MITCHELL & Co.

Respectfully submitted.

(S) ROBERT V. FLEMING,
(S) CLARENCE CANNON,
(S) CARYL P. HASKINS,
Executive Committee.

GENERAL APPENDIX
to the
SMITHSONIAN REPORT FOR 1960

ADVERTISEMENT

The object of the **GENERAL APPENDIX** to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by staff members and collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution from a very early date to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and, during the greater part of its history, this purpose has been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880, induced in part by the discontinuance of an annual summary of progress which for 30 years previously had been issued by well-known private publishing firms, the Secretary had a series of abstracts prepared by competent collaborators, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report of 1889, a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1960.

Reprints of the various papers in the General Appendix may be obtained, as long as the supply lasts, on request addressed to the Editorial and Publications Division, Smithsonian Institution, Washington 25, D.C.

The Science of Yesterday, Today, and Tomorrow¹

By W. F. G. SWANN²

INTRODUCTION

IT is within a period of less than three-quarters of a century, a period less than the span of life which many of my audience have experienced, that one of the world's most eminent men of science volunteered the idea that the discovery of nature's laws was ended, that the brain of man had solved the riddle of the universe, and that science was dead.

It is true that there were a few unopened, or partially opened, boxes which had come to light, and which seemed to contain things of some interest, but it was generally supposed that these things were, in principle, much the same as the things to be found outside. The contents of the boxes seemed to be in rather messy state. However, it was generally believed that if they were cleaned up and put in order, they would reveal nothing new. The job of cleaning them up seemed to invite little interest, so for the time being, they were left as they were.

And so, even as the great surgeon, having performed his major operation, leaves to a humble assistant the task of cleaning up and removing the stitches, so the man of science felt that his work was done, and that he might leave to lesser lights the task of polishing up the contents of those boxes and of finding out how they fitted together to useful ends.

But when the boxes were opened, it was found that many of them contained things of a nature quite unexpected. The things which were in the boxes did not behave according to the common sense of the day. They had to do with such phenomena as gases excited to emit light by electric discharge. By and large, they had to do with glowing things. If in those days there had been any radio tubes, they would

¹ The Charles S. Redding Lecture, delivered at the stated meeting of the Franklin Institute on December 16, 1959. Dr. Swann was honored at this meeting for his 32 years as director of the Bartol Research Foundation. Reprinted by permission from *Journal of the Franklin Institute*, vol. 269, No. 3, March 1960.

² Director emeritus, Bartol Research Foundation of the Franklin Institute, Swarthmore, Pa., and a senior staff adviser for the Franklin Institute Laboratories for Research and Development.

undoubtedly have been found in the boxes, together with all the paraphernalia of modern electronics. Indeed, many of the materials necessary to bring to light this important realm were there, but they were constructed on a scale too small to be perceived by the eye of man, so they passed notice as useless debris. In this debris would have been found the substances out of which today we make transistors which supply your hearing aids. In the boxes would have been found things which, by proper assembly, would have produced X-rays. Some of them would have contained substances like radium and all the multitude of atoms which today we know as isotopes; or at least, they would have contained the wherewithal to produce these things which today play such an important part in medicine and industry. In one big box there would have been found the sun itself uttering complaints that the man of science had given him no guarantee that he would be able to go on emitting light practically forever, that the physicist had provided no security for the maintenance of his bank account of energy, and that without it he was in danger of degenerating into celestial bankruptcy.

In those boxes would have been found all the ingredients necessary to produce atomic bombs and provide for the release of atomic energy in general. In them would have been found, in a form too small for the eye to see, all the mechanisms necessary to provide for the doings of the greater universe, for the behavior of the stars and the great galaxies of space with all their mysteries, including the continuous production of cosmic rays, and the like.

Truly, those men of science of three-quarters of a century ago, who left those boxes to the care of underlings for the unraveling of their contents, as the surgeon leaves to his assistants the task of cleaning up the patient, truly these great men of science died with a huge, if unknown, responsibility upon their shoulders. They are almost fortunate in having died before they were suspected of having left so much unfinished while they had declared that all was, indeed, finished.

Since man attained the stage of mentality in which he felt the desire to think about himself in relation to his surroundings, he acquired the ambition to understand nature. The basis of such an understanding is an elusive thing. It is by no means obvious. To put the matter in a nutshell, we may perhaps say that, in the past, to understand has been, for man, the ability to see in new phenomena which he studies, nothing more than the operation of the same principles that he has already accepted in the things which he has previously studied.

THE SCIENCE OF YESTERDAY

And so, in the beginning, the things which man learned to accept were the behaviors of beings like himself. Thus, in order to under-

stand how he and his surroundings could be controlled from the outside, he invented beings like himself who, indeed, had the power to control these things, even as he and his fellows had, on a smaller scale, power to control those who served them. Reversing the policy cited in Holy Writ, man invented these omnipotent beings in his own image, and with many of his own vices and shortcomings, as well as with his beneficent characteristics. The gods were angry, and they hurled thunderbolts. The gods were pleased, and they showered the earth with the blessings of spring. Anger and pleasure are such common attributes of mankind that they seem to call for no explanation in themselves. As regards a wider range of characteristics, the capriciousness of the gods, the uncertain temperament of the gods, and so forth, man, in seeking a basis for the acceptance of these things as normal, had to do no more than think of all the prima donnas of his age, and indeed of all the ladies of his own acquaintance. Alas, in those days there were no psychiatrists to analyze man's emotions as the outcome of more fundamental "causes"; and so mankind was content to "understand" in terms of the laws which governed his primitive feelings and experiences.

Early in his history, *Homo sapiens* became conscious of the efforts of his muscles, and the need for exertion in order that things should be accomplished. To bring stationary things into a state of motion, man found that he had to do something; and in the doing of it he became conscious of effort, so that there arose a vague concept of force. However, to push anything and to make it move, one had to come into contact with it. A man could not, by merely flexing his muscles, cause something at a distance to start moving. The force had to be transmitted from point to point in order to become effective. As a matter of fact, insofar as there is any difficulty in understanding motion at all, there is just as much difficulty in understanding it through the transmission of force from point to point in a medium as there is in understanding action at a distance. The late Sir Oliver Lodge once remarked that it is as yet an inexplicable fact that when one end of a rod is pushed, the other end moves, to which observation PUNCH replied that it is also an inexplicable fact that when one end of a man is trodden upon, the other end shouts. However, the layman readily accepted the philosophy that what the eye cannot see the mind need not trouble about. And so, the transmission of force through minute distances seemed to present much less of an obstacle than did its transmission over great distances.

THE AETHER, AND THE TRANSMISSION OF FORCE

The motions of the heavenly bodies became explained in the hands of Newton as motions which should be thought of as caused by

"forces" whose origins were in the heavenly bodies themselves; and while Newton himself would probably have taken a more philosophic view of the meaning of this statement than would many of his followers, those who wished to "understand," and had faith in the meaning of such understanding, felt, for the reasons I have already stated, unhappy about the acceptance of such a philosophy. They demanded some kind of a medium permeating all space between the heavenly bodies, a medium which could transmit the desired force. Later, this medium was charged with the duties of every conceivable kind of phenomenon by which one body appeared to influence another body at a distance. It became charged, among other things, with transmitting the light and heat of the sun to earth, and later it was charged with the transmission of radio waves. It was natural to try and understand this medium as something like a solid or a liquid, or a gas of our common experience, but alas, the demands on it did not harmonize with any of these characterizations. And so this medium, this "aether," as it was called, remained as a mystery. As long as one did not inquire too much about the mechanisms of its activities, it served as a balm to the conscience of common sense in seeming to relieve us of the terrors of action at a distance. Many were the attempts to provide inner mechanisms by which man could understand, in terms of the common sense of the day, all that seemed to be happening; but the mechanisms for different activities were inconsistent and all that remained was the apparent potentiality of transmitting something from one place to another with a finite velocity, even though one did not know what the something was which was transmitted. It was with this dilemma in mind that, some years ago, I defined the aether as a "medium devised by man for the purpose of transmitting his misconceptions from one place to another." It was during the period of prohibition, and I added an observation to the effect that "of all subtle fluids invented for the stimulation of the imagination, it is the only one which, so far, has not been prohibited." Later, alas, it also became prohibited, when the theory of relativity came upon the scene, declaring that it had no substance in reality, was inconsistent in philosophy, and was a useless encumbrance to the brain which tried to use it.

And so, it came about that insofar as it was meaningful to speak of one body as "acting upon" another, one had to accept "action at a distance" as something which, while dubiously respectable, was not a thing to be talked about in polite scientific society. I think, however, that we must realize that with his banishing of the aether to the realms of nonsense, man took one of his first steps in removing his ideas from the realm of popular understanding in terms of the everyday experiences of the times.

THE PRINCIPLE OF PREDETERMINATION

In this evaporation of some of the elements which were part and parcel of the intuitive thinking of a hundred years ago, there yet remained one principle which man was loath to discard. This principle invoked the idea that, at any rate as regards the inanimate world, that which is happening now determines that which will happen just a little later. And that which happens a little later determines that which will happen still a little later, and so on, ad infinitum. It is the principle of predetermination. It had its most explicit exemplification when science, through the activities of Newton and his contemporaries, described the motions of the heavenly bodies in terms of the now well-known laws of astronomy. The concentration was on what we call the laws of motion of the bodies. These took the form of what are called the differential equations of motion. However, it is sufficient to say that these laws were such that, if you specify what exists now, they tell you what will be found just now—at the next moment, that is—and so on, ad infinitum. If you asked what must be expressed now, the answer, in terms of Newton's laws, is to the effect that you must assign a position and velocity for each one of the bodies whose motion you wish to discuss. In terms of these positions and velocities, the future is determined completely in terms of the present. In order that you should not derive too much comfort from this statement, however, I must remark that if you should specify the positions and velocities of the bodies a thousand years hence, those laws will equally well serve to determine where they are now. It is hardly polite to destroy your comfort in the belief that the present determines the future by asking you to accept a doctrine to the effect that the future also determines the present. I once worried myself about the problem of why, if I am to understand memory in terms of the present as determined by the past, I cannot also remember the future, if the laws work both ways.

The great success of the classical astronomy of Newton and the discovery of the atomic nature of matter and of the fact that the atoms themselves are composed of what we call particles, made it almost inevitable that man should try to understand atoms and their doings in a crude way by picturing them as models of the solar system itself on an enormously reduced scale; and so, some three-quarters of a century ago, there arose atomic theories based on this idea and carrying with them, therefore, in principle, the laws of predetermination. Perhaps I should pause for a moment to state what, in the last analysis, is indicated by the acceptance of such a principle. The matter is illustrated by the story of a man and his slave.

It appears that there was an ancient noble whose belief in predetermination was very firm. And the noble had a slave who stole some of

his master's possessions. For this sin, the noble made preparations to chastise his slave. However, the slave, being of a wily and ingenious disposition, said: "My master, you must know that I am not responsible for this sin which I have committed; for according to the philosophy to which you subscribe, it was preordained that I should steal this, your possession." However, the master replied: "Yes, my slave, that is indeed true; but by the same token, it was also preordained that I should beat you for your offense." I commend this principle to those who have charge of the destiny of youthful delinquents.

Anyone who subscribes to the principle of predetermination, and who is confronted with a situation in which a system suddenly departs from the course predicted for it by the laws assumed, would have but two views of the matter open to him. He could deny the truth of the laws, or he could regard the occurrence as a miracle. This is, indeed, no more than a crystallization of the meaning of the word "miracle."

THE SCIENCE OF TODAY

THE MIRACLE OF ATOMIC SCIENCE

Now, in opening up the boxes of which I have spoken earlier, it was found that those things therein which were pertinent to the structures of atoms and molecules do not behave according to the principle of predetermination. They do not behave according to that smooth running of things which science had come to idealize. Every change which the atom experiences is a sudden one, with no clear-cut relation to the past, and no promise as to the future. Every change is a miracle in the sense in which I have sought to define that word. Moreover, it seemed, to most physicists, impossible to devise any laws consistent with the facts and according to which changes in atoms and in the realms immediately dominated by atoms occurred in any strictly predictable manner. The best that could be done was to invoke the concept of averages and to devise laws which told the chance that any particular occurrence would happen under certain assigned conditions. The laws were analogous to those which the insurance specialist uses when he predicts the fraction of all the people over, say, 50 years of age who will die in the next year. He cannot predict what will happen to any individual, but he can predict with considerable certainty what will happen to groups of individuals. In a sense, we may say that the whole quantum theory of today is a crystallization of the best laws which man has been able to devise for describing the nature of miraculous happenings. Of course, you may well say that if the insurance man should consult the physician of each individual and should order continual tests to be made of the state of health of each individual, then he could approximate with some certainty to accurate predictions as regards the individuals. You may

say that there is really no miracle about this matter. His uncertainty as regards the individual is simply something founded upon his ignorance of the complete story and of the impracticability of supplementing his knowledge to the end of making detailed predictions. And so you might think that the same thing would apply to the atom, and that, if you would only work hard enough to invent a more complete set of laws to govern its actions, the complete life history of every atom would be known and there would be no need to invoke miracles. However, physicists have worked very hard in an endeavor to do something of this kind, but without success, and the nature of their thinking is such as to convince many of them that complete success could never be attained, and that, as regards the atomic realm, we shall always have to put up with miracles. And now we are confronted with a curious psychological paradox. The average man of science, secure in the conviction that, as regards matter in bulk, nothing miraculous ever happens, is perfectly content to accept such happenings in the atomic world. Miracles on the scale of size of anything which we can see would be an abomination to him, but happenings which he cannot see, which the mind can only think about, but which he believes to occur, are acceptable. However, he avoids clash with his conscience by refusing to give them a name. Perhaps a still more curious thing is that with the advance of experimental techniques, man can actually observe certain of the miracles of the individual atoms; but here he feels his activities so far removed from anything to do with mankind that again his philosophical conscience makes no protest.

I feel it quite safe to say that if I should describe to any intelligent layman who was unacquainted with mathematical physics the principles according to which our so-called laws of atomic and nuclear structure operate; and if I could get my message across in a very short time, so that the layman would not become inveigled step by step into this way of thinking without encountering at each stage more than his philosophic conscience could swallow, I think that if I could do this, the layman would have to admit that the occurrences permitted in nuclear physics are, in terms of his normal criteria of common sense, more abstract and bizarre than any occult phenomenon which had been said to have occurred and which, under that name, he would probably dismiss immediately as evidence of insanity in those who subscribe to it.

During the last three-quarters of a century, science has brought forth many marvelous things which seem commonplace today and which have not startled mankind unduly at any stage of their development because their development has come upon us gradually. If, a hundred years ago, someone had awakened in the morning to find

in evidence an apparatus which enabled him to hear the voice of a man speaking in Paris; if, as he listened, he saw an airplane overhead, and if, on going into the street, he found vehicles dashing about without the aid of horses, he would surely think that he had come upon an age of miracles as remarkable as any of which he had read in the past. However, these things are no longer miracles to him because the scientists have told him that they know how it all happens; but when he gets down to ultimate fundamentals, even the scientist himself has to base his understanding upon processes which, if he could suddenly convey their nature to the layman, would have to be regarded by that individual as miracles in terms of his natural criteria of common sense. It is the miracles of the atomic and subatomic world which determine the activities of things on a larger scale, where their activities come to the attention of all of us, as symbolized by that docile entity "the man in the street." This man hears of the atomic bomb, so like an enlarged version of one of the urns of the Arabian Nights, urns from which, as the result of proper incantations, terrifying beings emerged. He learns that two apparently inert pieces of uranium of the same kind, on being brought suddenly into close proximity, explode in a manner such as to emulate all the furies of hell, pouring forth all sorts of evil things in the form of poisonous radioactive radiations and the like. It is as though these two pieces of metal, on being brought together, became infuriated by each other's presence and, in their anger, revealed all the evil that was within them. Indeed, from the standpoint of overall results, the performance of these two innocent pieces of uranium surpasses, in immeasurable degree, all the mysteries described in the immortal book of Arabian fairy tales. And our man in the street, on witnessing the atomic bomb, might well say "Here, at last, I find a real miracle—a miracle which can be repeated at will." But the men of science tell him that they know all about what has happened and that there is no miracle. In this they play some deception on that layman, for, if they could reveal to him the picture of those more subtle atomic processes which are involved, he would be likely to exclaim "But these processes in terms of which you explain the bomb are, to my way of thinking, miracles themselves." And the man of science, if honest with himself, will have no choice but to reply, "Yes, my friend, that is indeed true to your way of thinking; but to me, who has lived with these subatomic phenomena so long, the phenomena have ceased to carry with them the stigma of the word 'miracle.' And so," says the man of science, "I ask you to be content in my statement that all is really well in the philosophy of the matter. Then you will not be worried unless you think too much. I shall be content on account of the fundamentality of my knowledge and the broadness of my philosophy, while you shall seek refuge for contentment in the depths of your ignorance."

And so, after a time, the man in the street learns to regard the behavior of the atomic bomb as something not too much to be marveled at, and he accepts it as he has accepted radio or as, at an earlier time, he had accepted the ordinary phenomena of electricity, the running of streetcars as the result of something peculiar happening in copper cables which, by some mysterious means, are said to transmit electric power. He accepts these things as in a still earlier epoch he accepted the motions of the heavenly bodies as phenomena not to be denied, phenomena familiar in the experience of all, but phenomena which did not seem to weld together with the idea of action through contact, which the naive intuition of the day seemed to regard as a natural haven of contentment in the understanding of all things.

Now, in spite of all I have said to persuade you that we live in a world of miracles, you will perhaps be unhappy about my definition of that term. You may prefer to regard a miracle as a thing of such unusual occurrence, that the fact of its having occurred at all is open to doubt. You may then maintain that atomic phenomena are not miracles because they are always occurring, and their continual occurrence provides, in its totality, for the phenomena evident around us. If you say this, I fear that the Lord hath delivered you into mine hands; for in this sense, practically all the phenomena of the atomic world would indeed be miracles to any supposed inhabitants of the atom.

Consider the emission of an X-ray from an atom. Even if, in imagination, you lived on one of the atoms which compose the part of the X-ray tube from which the X-rays come, so rare would be the emission of a ray from an individual atom that you would be put in an atomic lunatic asylum if, as a resident of such an atom, you maintained that any such phenomenon had ever occurred. Only because there are so many atoms does the physicist observe a strong emission of X-rays from the X-ray tube. And so, what is a miracle to the resident of the atom is no longer a miracle to him who observes a multitude of atoms. A similar remark applies to practically every phenomenon in atomic physics.

A cosmic ray, passing through this room, detaches an electron from an atom here and there, and by observing this phenomenon we investigate and measure the rays. Yet, to the individual atom, this theft of an electron by a cosmic ray is such a rare event that the chance of its happening to any particular atom in the period of, let us say a day, is no more than the chance that one of you would be murdered in that day if, with the earth at its present population, only one murder were committed in 300 years.

And so it is with all the happenings of atomic physics. And yet it is these miraculous happenings which, in their totality, produce all the interesting things which our coarse-grained senses observe. And

to these coarse-grained senses there is no miracle; everything happens smoothly with apparent certainty of prediction.

HARMONIZATION OF DIFFERENT DOMAINS OF SCIENCE

So far I have concentrated on laws and phenomena associated with what is customarily called the realm of physics. Even here I have to admit that theoretical physics is at present in rather a messy state. When, however, we contemplate the wider realms of knowledge embracing biology and what we have recently learned in astronomy, there is much to be desired. Our knowledge of nature is like that of a world of little islands and countries, separated from each other, each being governed, apparently, by its own laws, with no very satisfactory relationship between the laws of one country and those of another. In the affairs of men one can tolerate a situation of this kind. One does not expect the laws of all nations to agree, although one has a hope that in time they may. In science, however, we have sufficient respect for the design of the universe to believe that there is a unified scheme covering all realms of phenomena, and indeed, in the last analysis, the affairs of mankind as a particular case. The idealistic philosopher will not cease to search for such a scheme and it is right that he should do so. If and when he succeeds, however, it may well be that we shall find that the scheme which he has found is of very little practical use.

As a matter of fact, a very general scheme covering as particular cases a wide range of phenomena dare not, in the nature of things, be very specific about any one of the phenomena. It can only be specific about things which are common to all the phenomena; and of these there may be very few. The very general theory will be like a very evasive politician. As an active member of a group devoted to economy in public affairs, you come to him and ask what he has to say about expenditure on armaments, hoping perhaps to get a detailed budget, stating how much may be assigned to this and to that, and how much may be saved from armaments for peaceful projects. However, the reply you get is something like this: "Our expenditures should be such as to maintain a stable and safe economy which reflects security in all that pertains to our lives." Well, you don't get very much out of that; and as you leave, and as you pass through the door, there comes a man fanatically devoted to military preparedness who wishes to ask about budgets designed to secure the most up-to-date equipment for all that pertains to war; and on posing his question, the politician again replies: "Our expenditures should be such as to maintain a stable and safe economy which reflects security in all that pertains to our lives."

Any statement which has to cover a wide range of circumstances cannot, in the nature of things, say much which applies to all; and indeed, when the range of circumstances is infinitely wide, the safest

thing is to say nothing. However, if you are expert in the art of oratory, you will be able to say it with force and conviction.

Let us consider, as an example, a physicist who studies the science of electrodynamics and gravitation separately and later desires to mold them into a common theory. It will be unnecessary for us to think of gravitation in the light of the general theory of relativity. The old Newtonian concept will suffice.

Our physicist studies the laws of the heavens and finds that they conform very well to the Newtonian law of gravitation. I point out to him that some of the celestial bodies are magnets and that their attractions for one another will be modified in form and degree by this circumstance. The physicist replies quite correctly that the phenomenon is of very small numerical magnitude and that he proposes to neglect it. Next day, I find the physicist in his laboratory studying the attraction of magnets and of electrically charged bodies for one another. I point out that these bodies also attract gravitationally, and that he should take this into account. Again he replies, quite correctly, that in these experiments the gravitational effects are so small compared with the electromagnetic effects that he is justified in neglecting them. In other words, in one problem of the universe, our physicist neglects the phenomena which are the whole source of interest in another problem, in which other problem, moreover, the phenomena dominant in the first problem are now negligible.

Now neglect of the small gravitational effects in the electromagnetic experiments is justifiable so long as one maintains the principle that the gravitational effect is, in actuality, there. If the gravitational effect is omitted, even in the formulation of the general principles of the subject, on the basis of its being too small to detect in electromagnetic experiments, and if the laws of these experiments are, therefore, placed on the statute books without it, they will possess no power to recognize it in any other phenomena of nature where the circumstances may be different. They will, in fact, be in danger of actually denying its existence in any field whatever, and of rendering its subsequent discovery in the astronomical field a phenomenon puzzling to comprehend, and apparently antagonistic to the science of electrodynamics.

Now, if a general theory embracing electrodynamics and gravitation is provided, it may take care of problems in which gravitational forces and electrodynamical forces are equally important even though nature may present us with no such cases where they are of equal importance. Such a general theory is able to extrapolate itself to one end to a case where gravitation is unimportant and electrodynamics is all important and to extrapolate itself also to the other end to a case where the relative importance of these respective phe-

nomena is reversed. The theory thus provides a bridge by means of which the two extreme cases are seen to be not inharmonious, whereas individual theories for each case, formulated on the basis of all that experiment can reveal, would appear at first sight mutually antagonistic.

However, the language of the bridge which spans electrodynamics and astronomy may not be very simple when asked to speak the story of either of these subjects separately. If I concentrate on the domain which is astronomy, I shall tend to paint pictures and make models characteristic of that end of the bridge, pictures which emphasize very strongly to my intuition the salient phenomena of astronomy, but pictures which would have to become more and more out of focus as I walked across the bridge to the realm of electrodynamics. And when I reached this realm, I would find them completely out of focus and unable to convey to me any meaning at all. On the other hand, if I start at the end of the bridge which is electrodynamics, and do the same kind of thing, I shall paint pictures and make models appropriate to the most important phenomena characteristic of that end. And these pictures will, in turn, become more and more hazy as I cross the bridge to the end concerned with astronomy. If I am a philosopher, and willing to realize the limitations of my pictures at both ends of the bridge, I shall not be disturbed by their becoming hazy as I cross from one end to the other. However, if I am a nonphilosophical astronomer, the pictures which I have painted, and the models which I have created to understand my subject will be very fundamental to me; and if I tamper with them my mind will protest that what I am doing produces nonsense. A similar thing will happen for the nonphilosophic student of electrodynamics at the other end of the bridge. He will create his pictures and the elements of his creation will be for him the basis of reasonable understanding. Thus while the philosopher will be able to cross the bridge in contentment in either direction, adjusting himself to the scenery on the way, the nonphilosophic astronomer and the nonphilosophic student of electrodynamics will feel that their realms are quite distinct and that the laws of one subject have no connection with those of the other. While the general formulation of the philosopher will extrapolate harmoniously, both ways, from one end of the bridge to the other, the more specific pictures and models appropriate to the two ends will not extrapolate, for the elements of these pictures and models which are prominent in the phenomena at one end may be of negligible importance to the phenomena at the other end.

And yet, at each end of the bridge, the philosophically imperfect pictures appropriate to that end may be more useful than the generalized picture painted by the philosopher. Thus, 300 years ago, many believed that light was composed of rays which traveled like arrows

from source to image. Later came the wave picture of light, and later still the picture characteristic of the quantum theory. However, even today, the optician who insisted on making spectacles with philosophic regard to all the features of the quantum theory would soon go out of business. No; the optician makes his spectacles with no thoughts in mind other than those of his forerunners who thought entirely in terms of rays for all optical phenomena 300 years ago.

It becomes increasingly important that the physicist, who has attained success in much of his specialized field by invoking certain principles, should not fail to inquire as to the extent to which those principles may play a leading role in other domains in which, perhaps, as yet they have not been utilized.

THE ROLE OF PATTERN

The atomic physicist has been brought up to think in terms of particles with what he calls forces between them. He learned to do this in the early birth of astronomy and has clung to the procedure. In the beginning the procedure was to seek the laws of motion of the particles. Thus, if, in astronomy, one gave the positions and velocities of the heavenly bodies at some instant, the laws were such as to spell out step by step how each of them moved; and in terms of those positions and velocities originally assigned, tell the inevitable story of what happens subsequently. In terms of positions and velocities taken as starting points, the system was one of predetermination. All motions calculable in this way, and consistent with some initially assigned sets of positions and velocities, were regarded as possible. Of course, different starting points resulted in very different developments. In some cases we should realize a body like a sun with other bodies traveling in circles or ellipses around it. In other cases, we should have bodies coming in from outer space, visiting the sun for a brief period, and returning to infinity by other paths. In still other cases, bodies would interweave their ways in complicated paths among their fellows. There were, in fact, innumerable patterns which could evolve from different starting points, and each of these patterns had its own peculiarity inherent in its own particular starting point. Thus, all sorts of different astronomical universes were possible insofar as the motions of the bodies which constituted them were concerned. However, the custom was not to concern oneself too much with the patterns as fundamental, but rather to regard them merely as the consequences of the particular positions and velocities which, by chance, had been originally specified.

When science came to regard atoms as groups of particles, the same kind of procedures was envisaged; although the laws of motion of the particles were spelled out in different fashions when other things like electromagnetic radiations became involved and claimed a place for

the harmonization of such things as light, X-rays, wireless radiations, and so forth.

And as science advanced, particularly in the atomic realm, it became evident that the theoretical procedures born of astronomy were becoming increasingly unsuccessful in providing a description of all that happened. It became evident that the procedure which was likely to work was a procedure in which one concentrated more on inquiring as to the patterns which can exist in nature, patterns of motions of particles, in the first instance, and later, patterns of more abstract things which the physicist called "psi functions." The old laws of motion of particles formerly occupied the central stage of our interest. Any pattern to which they led could be regarded as permissible; and of the permissible patterns, there was an infinite variety. In the new era of atomic philosophy what remained of the old laws of motions of things was relegated to the service of limiting the patterns which could occur. The fundamental duty of these old laws, as dressed in their new garb, was to declare as meaningless all patterns but a limited set, the set which could be evolved out of them. The fundamental bricks of nature's structure were patterns which, born of these laws, dictated the things which could occur as distinct from those which could not occur.

The bricks of nature—the atoms, the molecules—were, in principle, more like a set of oriental rugs than minute astronomical systems. These rugs, indeed, were only symbolic and with them there went a scheme of interpretation of their significance. There is a faint analogy between these rugs and the oriental rugs which adorn your houses, for I believe it is a fact that the various patterns and subpatterns in these rugs are created with interpretable meanings.

And so, in science, what had formerly been laws of motions of particles were transformed to laws which determined what patterns could exist in nature, and with this scheme of things there went a key for the interpretation of the patterns. It was indeed, a far cry from one who thought to understand these laws of patterns in the sense in which, perhaps, he may have thought he understood the laws of astronomy. If you ask a maker of oriental rugs in what sense he understands the meaning of the rugs, he may rightly reply: "I do not have the problem of understanding why these rugs exist. I and my forerunners created the designs ourselves, but we have endeavored to weave into them a symbolic meaning which reflects the relationships of things in the world around us. Why these things should be and why that which happens does happen, we know not. Our function is that of systematic catalogers of events, and our rugs are the symbolic catalogs."

Now, I do not mean to say that the citizens of Arabia who make rugs would say everything that I have put into their mouths if I started with them a discussion on the matter. All I maintain is that

they might have said it; and if, in the saying of it, they had sought to develop a systematic scheme symbolizing the ways of the atomic world, instead of the limited domain of living things and the immediate elements of their experiences, hope, love, fear, and so forth, they might have been on the way to doing something rather similar to what the atomic physicist is doing today. Of course, the atomic physicist has at his disposal that great logical scheme of mathematics which he can use freely in his designs, and he is not limited to the utilization of simple elements of geometry.

I have spoken of the patterns of atomic structure as being abstract things distinct from pictures of particles and other material things which may be around. However, the patterns appropriate to groups of atoms which constitute the things we see, come, in some of their manifestations, to assume actual shapes of things in the elementary meaning of that word. And so, today, we see patterns, born in the understanding of atoms, extending themselves into combinations of atoms—to molecules. Here the pattern is as yet unobservable to the eye, and its abstract form must be inferred from chemical behavior. But from molecules, pattern extends itself into large structures, into crystals where form is evident in that which can be perceived by the eye. And in this domain of crystals, pattern provides a rich harvest of phenomena which, in the role known as that of semiconductors, has, within the last two decades, revolutionized the world of electronics, and here man found that his colossal achievement in inventing the radio tube and all that goes with it, was already anticipated and beaten by nature in providing what we now call transistors, which reduce in size and increase in compactness all such electronic devices.

Pattern has always been evident on a large scale in biological structures, but now we find it playing a fundamental role, not only in things which can readily be seen, but in the seeds of life itself, in the chromosomes of the cells whose behavior is so vital in cell division, and in the transmission of hereditary characteristics. And through such processes, we may, in time, learn to comprehend that crowning achievement of pattern to be found in man himself, an achievement in which a single germ cell contains in itself a pattern which insures that the being to which it grows shall duplicate, not only the general form, but many of the characteristics of his ancestors. The substance of the individual dies several times during what we call the span of his life, but pattern goes on from generation to generation; and even an abnormality in the being, a crooked finger, or a prominent jaw formation, can survive in its pattern for a thousand years. One thing about man, even as he is evident to those around him, goes far toward being immortal. It is pattern.

RELATION BETWEEN THE SCIENCES OF YESTERDAY AND TODAY

To return to the title of this address, the science of yesterday was largely the evolution of blind discovery of phenomena, the discovery of fire, the discovery of the potentialities of the wheel, the ingenious combinations of circumstances and principles, which were ever before us, to the use of man. There was another crude but nevertheless practical and extremely ingenious ordering of the things of nature in the systems of laws formulated by Newton and Galileo, and later by the giants of science of the 19th century, culminating in a sensing of the potentialities of the newly discovered phenomena of electricity. These developments led to the formulation of the general principles of electrical engineering, the realization of the dynamo, the electric motor, and later wireless telegraphy, and so forth. Then, starting toward the end of the 19th century, came an era of new interests. Experimental researches resulted in the discovery of phenomena not continually evident to the eye of man, phenomena which could only be brought into existence by the efforts of his researchers. The behavior of the planets, the general phenomena which govern mechanical machines, were always displayed before mankind and awaited only the exercise of man's ingenuity to harmonize them, and use them to his service when possible. The phenomena of electrical engineering of three-quarters of a century ago were not things evident to the eye until researches ferreted them out and organized them into purposeful activity. The later developments beginning toward the end of the 19th century concerned the contents of the boxes of which I have spoken earlier. They concerned the discovery of the electron, the proton, X-rays, and allied phenomena of atomic behavior. These things were completely uneventful to the eye of man until research forced them out of hiding and caused them to reveal their activities in newly created devices which would not have existed except for man's activity. Having become released from their bondage of obscurity, it became clear that these strange new things had, all along, been playing a part in phenomena which had been available to man's viewing from time immemorial. Up to this time, the laws of chemistry were largely empirical as were the laws of biology. The laws of what we call physical astronomy, as distinct from those of celestial mechanics, were in a very scrappy state as regards consistency of understanding, and the things of greatest interest had not forced themselves spontaneously upon man's notice. However, the development of the great telescopes and allied equipment presented an entirely new challenge for the understanding of things and behaviors vastly different in both scale and nature from those which, up to that time, had been the only things displayed for man's curiosity. And it came to pass that the new discoveries in connection with atomic laws went far toward pro-

viding for these things an understanding which would have been impossible without them. These same discoveries of the atomic realm did much to provide a more complete picture of what was going on in chemistry, and even in biology.

THE SCIENCE OF TOMORROW

And here we stand today. We have a consciousness of vast accomplishment in the interplay of what we call fundamental experimental research and fundamental theoretical research. Much harmony has been brought into things which would otherwise be obscure; and yet, the returns of the harvest of discovery have tended to reveal so much more to be fitted into the scheme and have given evidence of so much more yet to be discovered, that the expected labors of the future may well outweigh all those of the past. And what direction may these labors be expected to take in this era of the future—in this science of tomorrow?

While there is much yet to be done in correlating and enriching all that is known about what we call the material world, I feel that before long, we shall have to face the problem of the nature of life and of all that goes with it, if real progress is to be made. We cannot forever keep the laws of dead matter separated from those of living things; for after all, everything that happens as the result of our efforts in the utilization of what we have already learned must be initiated by the mind of man. I can imagine the heavens to go on their courses without any attention from mankind. I can be happy in the thought of a continual process of activity which, in its gross aspects at any rate, follows the kind of deterministic behavior which, a hundred years ago, might have been thought to be the "way of life" of all nature. But if, today, I make an atomic bomb which does drastic things, it is I who formed the decision to make it; and in so doing, I interfere with what would have happened had I not made this decision. At this point, the mind of man seizes upon the otherwise smooth running of things, and, in some way, that which is in my mind interlocks with inanimate nature to direct its course.

THE ROLE OF NEW ENTITIES

And in facing the necessity of bringing harmony into realms which today stand apart, what has the experience of the past taught us? We have a clue in what has happened in the domain of atomic structure itself. There was a time when all we had to work with were atoms regarded as indivisible things, without any properties other than were provided by empiricism as demanded by the laws of chemistry. No progress was being made in understanding the laws of spectroscopy or the laws which related the elements to one another.

Even the periodic table was an unfathomable mystery. Then came the discovery of the electron and the proton, two entities whose existence had not before been recognized, and at least a promise of further understanding was achieved. It was a faith in this promise which caused many to believe that the end of discovery was near. However, a barrier to further progress was soon reached. Many had wished to invoke the possibility of another kind of particle—a neutral particle—but conservative science, having with reluctance accepted two new things, the electron and the proton, smaller than the atom, looked with great distaste upon any upstart who wanted more atomic bricks to play with; and it was not until, through experiment, a neutral particle, the neutron, was proved to exist that progress went ahead with leaps and bounds.

We can readily understand the hesitancy of science to accept a neutral particle. One had almost come to regard as self-evident the principle that all atomic forces were electrical, and how could a neutral particle exert a force on anything or, indeed, how could it be influenced by anything? In the spirit of the times it had to be regarded as a completely dead entity. Perhaps the greatest clash with convention was the recognition of the fact that this entity, dead in the sense of all understandable happenings, could indeed play a part in its own way, a way so foreign to anything which was in the conventional picture. It was not so much by the fact that the neutron represented a new particle that science became disturbed, but rather that it represented a new set of relationships between things, a relationship which was not in the picture before. One had to admit what are called nuclear forces as distinct from electromagnetic forces—a new world of law and order. And what was more astonishing, one had to provide for interlocking relationships between this new domain of phenomena and the old domain which was so unlike it, and which, up to this time, had claimed authority over all nature.

HARMONIZATION OF THE SCIENCE OF TODAY AND THAT OF TOMORROW

And so, in contemplating the harmonization of life with what we call the laws of inanimate matter, I expect to find a new set of laws, laws which do not deny anything we had before except in the denial of the claim of those laws to finality. And I expect to find these new laws interweaving with the old knowledge in such a manner as to produce a more comprehensive whole, a whole in which all sense of barriers has become dissolved in an all-embracing harmony. For many purposes it may be convenient to keep the new domain separate from the old, as the maker of spectacles keeps his science of geometrical optics separated from the quantum theory of light; but there will be bridges connecting all parts of the new territory with the old domains in such fashion that he who travels across these bridges will

have no sense of sudden change; and even as one who travels from tropical regions to the poles can accommodate himself to his satisfaction at each stage of the journey, so the philosopher, in traveling over this wider domain which I envisage, will find himself content wherever he may be.

In developing the foregoing thoughts I have called attention to the rapid advance which took place in physics itself once one was willing to accept a new particle, the neutron, and furnish it with the wherewithal to operate. Now I do not expect it to be necessary to find a new particle which will cement the old materialistic realm with the realm of life and all that goes with it, but I may expect to find the formal recognition of some kind of a new entity differing from those which we have encountered in physics. I do not necessarily expect that this entity will be something which can be described in terms of space and time, although I shall expect it to be accompanied by well-defined laws of operation which provide, not only for the activities peculiar to its own purposes, but for the possibility of cementing it logically with the knowledge of the past. We must not be too astonished at the invocation of an entity which does not call for expression in terms of space and time. After all, I may speak of such things as good and evil without accompanying them with coordinates x , y , z , t , to express where they are and when they were there. For the sophisticated physicist, I may recall that even the coordinates which represent Fourier amplitudes in the analysis of radiation in an ideal box are not coordinates of a material point in ordinary space, but, as coordinates in an abstract, multidimensional space, they perform a useful service in physics. In the last analysis much that is spoken of in the quantum theory of physics involves concepts having little to do with the old conventional notion associated with the expression of all relevant concepts in terms of some thing or things having positions at certain times. I shall not be surprised to find the new entity playing a part in the survival of pattern, so dominant in living things. I hesitate to limit its potentialities by giving it a name already appropriated and endowed with properties of vagueness too foggy to be permitted in a scientific discussion, and so I will not call it by the name "soul." If it is to be of service, it must not shrink away from its duties and take refuge as part of high-sounding sentences. Its functions and modes of operation must be well defined and it is only natural that in conventional science it will have to go through the process of skeptical criticism which has fallen to the lot of all its predecessors in the materialistic realm. I should expect to find it play a role in those phenomena which for long have lain in the borderland between what is accepted by all and what is accepted only by few, even though representatives of the few may be found in all periods of man's history.

I refer to such things as extrasensory perception, the significance of the immortality of man, clairvoyance, and allied phenomena, and the significance of the fact that our universe exhibits what we may call a planned design, whether or not we are willing to admit the hazy notion of a planner, or say what we mean by that postulate.

PREDETERMINATION AND A PLANNED UNIVERSE

Perhaps the existence of the universe as an entity with strongly planned features provides the greatest argument against use of the undeniable fact that if we are willing to work hard enough and involve ourselves in a sufficient complexity in mathematical expression, we can possibly regard any universe as operating on a principle of predetermination. In general, the principle invoked in such an arbitrary manner may rule out many notions which seem so important in the life of mankind by regarding everything as inevitable, even as in the parable of the slave and his master at the beginning of this lecture the theft by the slave was inevitable and the beating received for it was also inevitable. If the universe were a chaotic affair without any of the properties which I have associated with the word "planned," there might be some sense in falling back on predetermination, but to invoke such a principle with things as they are is something like asserting that a cathedral of great beauty, which I had not seen before, was formed by the accumulation of dust in an accidental manner through the ages.

NEW DOMAINS FOR SCIENTIFIC INVESTIGATION

In discussing such matters as I am now venturing near, I think it is essential to avoid all theological doctrine as a starting point. I would rather see a theological doctrine emerge spontaneously as part of the overall scheme of nature, than I would see the workings of nature forced into a frame provided by a preconceived theological doctrine as a starting point.

In the past it has been a tradition of mankind to divide phenomena into two classes, those which may be investigated, and those concerning which we should not inquire. Between these two sets of phenomena there has been a barrier, and to cross that barrier was a sin against dogma or, in less solemn vein, a violation of sound principles of research only to be undertaken by those who are a little queer. As times progressed, this barrier has shifted, so that all astronomy now lies on the respectable side of it, in spite of the fact that 300 years ago much of it lay in the forbidden region, where also much of the embryonic science of chemistry was to be found. Today, chemistry is thoroughly established in the unrestricted region.

Even as many radicals become conservatives when they rise to power, so the science of the materialistic age, much of which lay on the

dark side of the barrier in the past, on becoming promoted to the free side, started to fortify still further the barrier which it had passed, so that things which did not readily find a place in its philosophy were held in the forbidden region. Yet behind this fortification of division which materialistic science itself has strengthened, stand the shadows of bygone days: the philosophies, the practices, the beliefs, and religions of ancient times, so vulnerable in many of the dogmas with which history had endowed them, that they oft fell an easy prey to the shafts of the newborn science of our era. The weaknesses in their armor bred a kind of conviction that all the wisdom of the ancient past was afflicted with the disease of superstition, a disease eating like a cancer into its whole system. Thus, many things which had been accepted for thousands of years were cast into the category of witchcraft. In the totality of these things there were, however, certain realms which, by virtue of the power which had supported them through the ages and because of their moral influence on mankind, stood with some security against the attacks of modern philosophy. These were, for the most part, the standard religions of mankind. There was a sort of truce between the two camps, a truce in which the realm of religion ruled on Sundays, while the materialistic philosophy governed the rest of the week. Some things, well accepted in the past, but apparently at variance with materialism, found themselves without the powerful support accorded to the great religions and so they were left to the ridicule of the new age. Some of these things which had been part of the doctrine of the churches of the bygone era found themselves disdained by the faiths which had nurtured them, and the guardians of the faiths became anxious to avoid contamination with practices which might be attacked with some apparent success by the warriors of the new age. Thus, healing by the laying on of hands, belief in the existence of spirit entities in our midst, even such were cast out by the religions which had originally fostered them, or if admitted at all, were retained as machinations of the devil, a being so beloved by the faiths that have created him that he has succeeded in holding his own in religion in the face of science itself. Naturally, at times he became very convenient as an agent to whom one could attribute all the shortcomings and inconsistencies in the faiths and dogmas which sought to rule, as well as his own shortcomings. In contemplating his identity, one is reminded of the little girl who, on being asked by her younger sister the question: "Is there really a devil?," replied: "No, of course not, it's just like Santa Claus; it's Daddy."

And now what we call orthodox science has itself grown a type of philosophy so different from the old science born of materialism that if it were forced to pause long enough to confess what, a hundred years

ago, it would have called its philosophic sins, it would find those sins no more free from materialistic criticism than much of the sins of philosophy which it has held behind the barrier.

THE ULTIMATE HARMONIZATION OF SCIENCE

Perhaps some day, not too far distant, orthodox science will find the urge to extend its domain of inquiry into regions formerly forbidden, and in the hope that all the phenomena of nature may find a place in one larger scheme of harmonization. I would hope that in this more comprehensive philosophy no man would have occasion to forsake any of the ideals which in the past he had fostered. When this condition arrives, I envisage a sage charged with the duty of answering the questions of all who would make inquiry. The musician will say: "Where is my art in this scheme?" and the sage will reply: "See, it is here, complete in itself, but joined by this bridge, in perfect logical continuity with yon domain which is the domain of abstract mathematics." And the priest will ask: "Where are the essentials of my faith in which I have lived and which has been my anchor of security?" And the sage will answer: "Cast your vision upon yon territory. There you will find it. It is joined by a bridge of great beauty to the domain of your arch-enemy, the domain which was formerly that of materialistic science."

And in this picture those things for which the mind and soul long shall no longer appear veiled in nebulous shrouds of uncertainty, but shall stand out as jewels adorning the greater universe in all its richness and splendor. And if some doubtful inquisitor should ask of the sage: "Where, in all this, shall I find the devil who has meant so much to me in my life?" he will receive the reply: "The devil—oh, the devil! He is in hell. You will find hell behind the old barrier, and the devil is the only occupant."

The Origin and Nature of the Moon¹

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[With 5 plates]

THE ORIGIN OF THE CRATERS

IN 1893 G. K. Gilbert, who appears to be the only student of the moon's surface in the course of the last century who had any sound knowledge of physical geology, published a remarkable paper on "The Moon's Face" [1].² He reviewed many features of the lunar craters and concluded that they were due to great collisions of meteoritelike objects with the moon's surface. In recent times, R. B. Baldwin in his book "The Face of the Moon" [2] reviewed the evidence concerning the origin of the craters, and since then it has not been necessary to reconsider the problem. Baldwin gives many references to the older literature and considers in detail the alternative hypotheses of a volcanic or a collisional origin. The volcanic theory of crater origin was advanced before modern scientists realized that meteorites fell on the earth, and it required nearly a century of discussion before astronomers agreed that most craters resulted from collisions.

Gilbert concluded that lunar structures are not similar to those of the earth; that the pattern of overlap is that to be expected for chance collisions; and that the moon has no structures similar to terrestrial volcanoes, if account is taken of the absence of erosion there. He recognized, however, that there are small craters which cannot be due to collisions and hence must be of some volcanic type, even though their shape is not that of terrestrial volcanoes.

Many questions relating to the moon are decisively answered by consideration of its overall shape and the nature of one of its principal features, the great Imbrian collision. There are many other subsidiary lines of evidence, but we can best begin our account by discussing these two important aspects.

¹ Reprinted by permission from *Endeavour*, vol. 19, No. 74, April 1960. Acknowledgment is made to the editor of *Sky and Telescope* for permitting the use of material published by Professor Urey in that journal in 1958.

² Numbers in brackets refer to list of references at end of article.

THE SHAPE OF THE MOON

Measurements of the elevations of the lunar surface have been made, but the methods of observation are difficult and not very precise: reliable evidence that it has an irregular shape comes from its dynamical motions. Textbooks on celestial mechanics give a formula for computing the difference in the moment of inertia about the polar axis (C) and that about the axis pointing toward the earth (A). From observed data $(C-A)/C=0.000\ 629$, whereas the theoretical value deduced from consideration of the moon's shape under its own gravitational field, the earth's gravitational field, and the centrifugal forces of rotation, is only $0.000\ 037\ 5$. The ratio of these numbers is $16.7:1$. If the moon has a uniform density, the observations require that the radius toward and away from the earth should be larger than that toward the poles by about 1 km. , whereas theory requires a difference of only about 60 m. This irregular shape must result in a difference in stress at the center of about 20 atm. , and this requires considerable strength of the material at the moon's deep interior if the density is uniform throughout.

If the density of the moon is not uniform, but varies according to latitude and longitude by a small amount, the irregular shape can be explained by a theory recently advanced [2a]. This requires the density near the poles to be larger than that about the axis pointing toward the earth. In this case, the strength of the deep interior need not be very great, and the center could be at a high temperature. But this variation of density with latitude and longitude could hardly have been preserved if the moon had ever been generally molten.

But could the moon have been molten even if it has a uniform density? So large an object can cool only very slowly, even in a time as long as the moon has existed, which we believe is about 4.5 eons (an eon being defined as 10^9 , or 1 billion, years). This age is assumed to be the same as that of the meteorites. Calculations of the loss of heat show that the center of the moon would lose little heat even in this length of time. If the moon were ever molten, its center would still be very close to its melting point and hence would not have the required strength to support the irregular shape [3].

The presence of the radioactive elements potassium, uranium, and thorium would increase the internal temperature, the effect depending on the amounts of these elements and their distribution. We know nothing about the distribution of these elements in the moon and have difficulty in estimating their distribution in the earth. However, if the heat being lost from the earth is assumed to be entirely due to radioactivity, we find that the total amounts of these elements in the earth may be very similar to that of the meteorites and that possibly less than one-half of them are in the crust. In the moon, a similar

distribution would keep the temperature in the deep interior above the melting point if it was originally molten. In fact, the entire interior out to about 0.8 of its radius would be at the melting point if the initial temperature had been that at which silicates melt. Such a conclusion is, however, inconsistent with the shape of the moon, and it must therefore have been formed at a low temperature.

We may ask whether the interior of the moon would be molten at the present time, owing to radioactive heating, even if it had been formed at a low temperature. There are uncertainties in the answer to this question. We do not know the concentrations of the radioactive elements in the moon. Possibly the concentrations in meteorites give the best estimate, though it is not a certain one. Calculations indicate that any metallic iron-nickel in the moon's deep interior would be molten, but we have in fact no evidence for the existence of metallic iron within the moon. The material of the moon is not a pure substance, and hence would not melt at one temperature: calculations indicate that partial melting of the silicates might occur. All these considerations can be reconciled only with the hypothesis that there is a variation in density with latitude and longitude. This explanation is consistent with a partially molten interior today, but inconsistent with a generally molten condition in the distant past.

Gilbert said, "During the whole period of growth the body of the moon was cold." This statement was made before the discovery of radioactivity. It has required much argument to come to the same conclusion again, and the problem is a critical one [3].

In 1862 Kelvin [4] wrote a paper dealing with the solidification of the earth from a completely molten state. At that time no other source of heat for volcanic processes was known other than residual primitive heat, and he therefore assumed a high-temperature origin for the earth. This belief has found its way into the textbooks, and it is now generally assumed that all objects in the solar system were once at very high temperatures. The discovery of radioactivity at the turn of the century made Kelvin's assumption unnecessary, but no reconsideration of the whole problem was made at that time. Possibly planets and satellites were formed at high temperatures, but we may now well ask what evidence exists for or against the hypothesis.

THE IMBRIAN COLLISION

A very great collision occurred in Mare Imbrium at some time in the past: the evidence for this was discovered and described by Gilbert. The collision directly modified a large fraction of the visible hemisphere of the moon. The region of Mare Imbrium is shown in plate 1, which is a composite picture of the moon: it is the large gray oval area at the lower right of the picture. It is also shown in plate 2,

which was made by projecting pictures onto a white sphere and then photographing the mare from a point directly above it. The lines indicate the positions of the Bay of the Rainbow or Sinus Iridum, a circular area before it, and the entire mare. Radiating from the circular area are many ridges, particularly toward the southwest: there are also many grooves in the surface, as can be seen on good photographs. Gilbert noted all these features, except for what seems to be an obvious relationship of Sinus Iridum to the rest of the pattern. The most reasonable explanation of all these details is that they are related and were produced by one event. The whole pattern is unsymmetrical, and hence one concludes that the colliding object arrived from the northeast at a substantial angle from the vertical, plowed a deep hole in the moon, and spread out some of its own substance and some of the lunar substance in a wide fan-shaped area and to great distances. The object probably came in through what is now Sinus Iridum and either produced this bay or destroyed one wall of a walled plain. Alternatively, a second collision of substantial size occurred in precisely the same region after the formation of Mare Imbrium. Two large collisions at the same spot seem most improbable, and hence it is most likely that one great collision produced the entire pattern.

A few of the ridges and grooves extend through the Jura Mountains to the northeast of Sinus Iridum. The principal pattern spreads out in a semicircular fan from the edge of the Carpathian Mountains on the east, to Plato to the west of Sinus Iridum. Mountainous ridges which point toward the circular collision area are found in and beyond the center of the moon's disk. High-density objects plowed through the walls of Ptolemaeus and Alphonsus and produced great grooves in the surface: these objects can reasonably be assumed to have been metallic iron-nickel. In Oceanus Procellarum there are many short ridges orientated in the general direction of the collision area. It is not clear whether some of the individual ridges and grooves belong to the system or not, but the overall pattern is entirely convincing.

The circumsurface velocity of the moon is 1.7 km. per second, and since the objects fell at a point some 1,000 to 1,500 km. from the point of collision, their velocity must have been of about this value. The broad pattern indicates that the object was moving at a velocity lower than that of sound in the material of which it is composed—in this case, some 5 to 7 km. per second. An object moving with relatively high velocity—say some 30 km. per second—would bury itself before the rear side received a signal that contact was made and would explode to give a symmetrical pattern. But if we assume a velocity less than that of sound—say some 2.4 km. per second, which is the escape velocity of the moon—the unsymmetrical pattern can be under-

stood. Vertical deceleration of the top of the object would occur, and this part could move off horizontally at some 1.7 km. per second: probably some would spray out sideways to produce a fanlike distribution. The object may have been a satellite of the earth-moon system or one moving in an orbit similar to that of the earth.

Whatever its nature, the object most probably produced Sinus Iridum, and hence passed between the two promontories of Laplace and Heraclides: the distance between these is about 230 km., and this is therefore the maximum diameter of the planetesimal. Gilbert suggested 100 miles for its diameter: other suggestions have been made, but on less direct grounds. Using 200 km. as a likely value, calculations of the object's kinetic energy can be made. Assuming a density of 3.5 g./cm.³ and 2.38 km. per second (the velocity of escape from the moon) for the velocity, the kinetic energy is 4.15×10^{32} ergs. This is equivalent to 4.6×10^{11} atomic bombs, equivalent to one for each 1,100 square meters of the earth's surface. The largest earthquakes are estimated to expend about 10^{24} ergs, and thus the Imbrian collision dissipated an energy more than 10^8 times as great.

A collision of this magnitude is completely beyond any observations which we have made, and deductions made from any scaling up of terrestrial observations would be most doubtful. It is better to take this collision as an observed fact and to try to learn something about large collisions from it. The object plowed in through Sinus Iridum; flattened out in the collision area; and raised a great bulging wave in the moon's surface in all directions, but particularly in the forward direction, that is, toward the center of the moon's visible disk. The affected area was badly broken up, perhaps even to the consistency of fine sand, and after the collision, part of the material subsided again, producing the shelf area between the inner and outer rings shown in plate 2.

It is possible that part of the lunar surface was lifted and then dropped as big blocks, forming the Straight Range, Piton, Pico, Spitzbergen, and the other mountainous mass indicated by the arrows in plate 2. The Alps, Caucasus, Apennines, and Carpathian Mountains may also be formed of this kind of material; the first two, in particular, look like fragments of this kind. It is, of course, possible that those mountains were part of the planetesimal. The Haemus Mountains must consist of fragments of the colliding body. The long grooves must have been produced by high-velocity and high-density objects plowing through the surface. Because of their high density, these materials must have been metallic iron-nickel, and they must have been part of the colliding object in spite of their great distance from the collision area. Such iron-nickel objects could hardly have formed a core of the colliding planetesimal: probably they were dis-

tributed as isolated objects, mixed with silicates, throughout the mass. They are reminiscent of the iron meteorites, and probably the planetesimal was similar to objects which produced the iron meteorites.

Other circular maria are Crisium, Nectaris, Humorum, and Serenitatis. A prominent scarp, the Altai Mountains, to the south and east of Mare Nectaris, is similar to the scarp around Mare Imbrium. The area between the mountains and the smooth mare is covered with great craters: it seems to be analogous to the shelf area in Imbrium. The Rheita and Borda Valleys and other grooves radiate from this mare, and may have been produced by high-velocity missiles. Baldwin believes there are radiating grooves around other maria. Partially covered craters are present in Mare Serenitatis. Probably all these circular maria were produced by great colliding objects which approached at differing angles to the surface. The highly unsymmetrical character of Mare Imbrium shows that in this case the planetesimal approached at a low angle. The other collision maria were probably produced by objects falling more nearly vertically and hence did not produce such a wide-angle fan of ridges and grooves.

THE TIME OF OCCURRENCE OF THESE EVENTS

Some of the craters on the moon must have been produced by meteorites, though we have little evidence for really large meteorites hitting the earth. Some of the large lunar craters were formed before the Imbrian collision and others afterward. Ptolemaeus (pl. 4) has walls that have been scarred by missiles from the Imbrian collision and are very low, as though they had been partly shaken down by this energetic event. Mountainous masses have fallen on other craters, as for example in Julius Caesar. Other craters, such as Aristillus and Autolycus lying within Mare Imbrium and Eratosthenes on the southern edge of this mare, are more recent. Whether Plato and Archimedes could have survived this great collision is doubtful. Similar relationships are evident in other maria. Theophilus and other craters in the neighborhood are more recent than Mare Nectaris. All these collisions were part of a single series of events; some craters were formed, then a mare, then still more craters, and so on. These craters and maria cover the entire visible surface of the moon so densely that the whole of it has been broken up. One would expect that during the time of this bombardment the earth would have been bombarded even more intensely than the moon, because of the greater energy of the collisions with its surface and because its gravitational field gives the earth a larger collision cross section. Such a bombardment would have destroyed all the terrestrial sedimentary rocks and should have left great scars on the continental shields. The oldest terrestrial rocks have been reliably dated at about 3 eons, while the meteorites are

about 4.5 eons old or slightly older. The intense bombardment which occurred on the moon must have happened more than 3 eons ago, and may well be a record of the final stage of the formation of the moon, the earth, and indeed of the solar system.

COMPOSITION OF THE MARIA

It has been commonly supposed that the maria consist of solidified lava. This is a natural assumption, since the maria are level, as we would expect fluids to be in the moon's gravitational field. It has been assumed that the lava flowed from the moon's interior, but a well-known line of reasoning shows that this is doubtful. Terrestrial lavas have temperatures not over $1,200^{\circ}\text{C.}$, which is a reasonable estimate of the melting points of basaltic liquid in equilibrium with the silicates beneath the earth's surface. This liquid cannot be much above its melting point, because if it was, it would melt the containing walls and hence cool until equilibrium was again reached. If such a liquid flows onto a cold surface the lava begins to freeze, and it is difficult to understand how it could flow very far without producing fairly high terminal walls. It should be noted that proponents of the ideas that the maria are of laval origin have postulated that the liquid flowed very great distances. The Oregon and Deccan plateau lava flows each cover about $500,000\text{ km.}^2$, which is smaller than Mare Imbrium. If the lunar features are indeed lava flows, they are comparable to, or even larger than, those on earth. It seems probable that some terminal walls would be preserved if the great smooth areas were in fact of this type [5]. Also, had the moon's surface been underlain by these vast quantities of high-temperature lavas, the great mountains would surely have gradually sunk into the moon's surface. On the basis of such arguments Gilbert concluded that the moon was cold when its maria were formed, and we can conclude that it has been cold in its outer parts ever since. There is no evidence that the mountains have settled into the moon's surface, and we can deduce from this that the lavas (if they are lavas) did not come from the moon's interior.

Gilbert believed that the melting was caused by the collision energy of the objects arriving on the moon. The collision energy per gram of an object arriving with the escape velocity of the moon ($2.38\text{ km. per second}$) is $2,800\text{ joules}$, and about $2,000\text{ joules per gram}$ are required to heat silicates to the melting point and then to melt them. Some energy would be dissipated as vibration, but some melting might occur. If the velocities were very high, volatilization would occur and something like a great explosion would take place. This is inconsistent with the unsymmetrical pattern of ridges as mentioned before, but nevertheless a velocity somewhat higher than the escape velocity is possible.

T. Gold [6] has suggested that the maria consist of deep layers of dust produced by the eroding effects of sunlight and particle radiation from the sun. He believes that such particles would move over the surface because of charges on them. A hopping motion is assumed to have moved them over great distances in the past and to move them in the same way at the present time. He points out that the many craters, large and small, in the southern regions have smooth, gray material within and between them, and that neither lava from the interior nor molten material resulting from collisions appears to be a reasonable explanation. Such reasoning prompts two questions. Do we think that liquid from the interior seeped up in all these places? If there were ever large quantities of liquid beneath the lunar surface, would not the more dense solid phase sink steadily down into the liquid until it was completely submerged?

However, the hypothesis that erosion was the main origin of the dust is unreasonable, for if this were so, all parts of the moon surface should have the same appearance, or this should at least be true of all equatorial regions. It is not true of the hemisphere that faces the earth and, as we have lately learned, emphatically not true of the back hemisphere. These facts make Gold's general hypothesis untenable, although some erosion of this type may be present and may modify the effects of other more dominant processes.

If spread over the moon's surface, the Imbrian planetesimal, supposedly some 200 km. in diameter, would make a layer 110 m. deep, and if it contained 1 percent of water by weight this would be enough to cover the moon to a depth of 3.9 m. This is a larger percentage of water than is contained in the meteorites or on and within the earth. Other planetesimals which produced the other circular maria could have supplied water also. Such planetesimals would be moderately explosive if they contained water or other volatile substances. These possibilities suggest that in addition to the materials which have already been discussed above as coming from these planetesimals, there may have been a vast dust cloud which spread finely divided materials over the moon's surface. This material, of course, would fall on the mountain slopes, but it does not appear to be there now. Did temporary rains wash it off? Or did the violent moonquakes cause it to slide into the valleys, as "fluidized" mixtures of gases and solids used in industrial chemical processes do? Gilbert remarks that many lunar features look as though they had been covered by a pasty material, and thought it was partially solidified lava. Perhaps he was right, and it is neither dust nor rubble.

To resolve the problem we should look for objective evidence. Anyone looking at the moon through even a small telescope is immediately impressed with the smooth character of the maria, but I am

convinced that merely looking in this way will never provide very detailed evidence. If only we could see the crystalline structure of the lunar rocks! Lava, especially basaltic lava, is a dense liquid of considerable fluidity which might push over and distort crater walls in its path. I can see no evidence for this having happened in Mare Nubium or Oceanus Procellarum. I have for the most part studied only pictures, but a little observing convinces me that gross features of this kind are not likely to be missed when good photographs are available. But lava must flow downhill, whereas dust can fall anywhere. The coloring in some photographs indicates a smooth hill over the eastern wall of Prinz and over the craters Hippalus and Weiss: other examples are less clear. On the other hand, the crater Wargentini is full to the brim with what appears to have been a liquid. Gilbert noted that Julius Caesar is filled as high as a breach in the southern wall and that Posidonius is filled to the height of a similar breach, which suggests that the contents of both were once fluid.

Mare Tranquillitatis has a very irregular shape and is very black. One would expect that the settling of dust would give the moon a uniform color or that color variations would be gradual. The boundary between the black of Mare Tranquillitatis and the gray of Mare Serenitatis in the western part of the latter is very sharp, and there appears to be no difference in level. In fact, Mare Tranquillitatis does look like a lava flow. Some of its craters—for example, Maclear—seem to be distorted. The fragments of craters in the western part of the mare look as though they may have been pushed about.

Possibly both lava and dust were produced by the collisions, sometimes one and sometimes the other. Possibly a planetesimal fell vertically and produced Mare Serenitatis and a pool of very dark lava which flowed into Mare Tranquillitatis. It had only a small content of volatile substances, and its material was distributed to only a limited extent over the moon. Then the Imbrian planetesimal, containing an appreciable concentration of volatile substances, fell and distributed gray dust widely. Possibly it was some other series of events. Gold's dust hypothesis has at least stimulated some serious thinking about the long-accepted lava hypothesis.

DURATION OF THE BOMBARDMENT

It is notable that there are no large craters of later date than the maria in the collision maria: in the case of Mare Imbrium this applies only to the collision area within the broken circle of plate 2. Theophilus and Piccolomini, near the shore of Mare Nectaris, and another on the Altai Mountains at the south are certainly postmare, as are other craters near the shores of other maria. These circular collision maria must have been fluid, that is, either true liquid or dust "fluid-

ized" by gas at the time the bombardment ended. A similar argument holds for the absence of mountainous masses in Mare Serenitatis. Had this mare been formed after Mare Imbrium, one would expect to find the scars of this collision scattered over the radiating ridges of the Haemus Mountains, to the south of the mare, which were obviously produced by the Imbrian collision. Further, the mountains in the region between the two maria are very well preserved, and have a radiating pattern showing that they are part of the Imbrian system (pl. 3). For these reasons I conclude that Mare Serenitatis is older than Mare Imbrium. But in this case the absence of a mountainous mass, similar to the Haemus Mountains, on Mare Serenitatis, shows that this mare was fluid at the time of the Imbrian collision. Lava would very quickly solidify to form a very rigid mass. Dust or sandy material can become rigid also, though it might not for some time have sufficient strength to support a massive mountain. The small craters in the maria are due to collisions that took place during the 4.5 eons that have elapsed since the occurrence of the very great processes which produced the maria.

These arguments indicate that the major surface features of the moon were fashioned in a very short time. Calculations based on the rate of cooling of solidified rocky materials show that only some tens of thousands of years are required for such pools of lava to cool: if some low-density froth or pumice floated on the surface the time could be considerably longer. (In this connection it must be remembered that the solidification of most liquids does not follow the same course as that of water, whose solid phase floats on the liquid: if a magic wand were to make water behave like all other common substances, the ice of the Arctic Ocean would sink and the ocean would freeze solid from bottom to top.) The consolidation of dust would require still longer. We have little experience on which to base a guess, but possibly much less than a million years would suffice—a surprisingly short time. It is possible that the objects which collided with the moon to produce its gross features were satellites of the earth-moon system. During some thousands of years, such objects would collide with the earth or moon, but objects traveling in orbits about the sun, when in the neighborhood of the earth would collide with the latter within some tens of millions of years, according to calculations of E. J. Öpik [7]. Objects moving in orbits about the earth should arrive at its surface with about the escape velocity of the moon.

The stone meteorites are immensely complicated structures, consisting of agglomerated sandy materials whose crystalline minerals were certainly formed in a body different from those in which they are now found. Some collisional process such as occurred on the moon may have produced the highly fragmented crystals that we find

in these meteorites. Using three radioactive dating methods—based respectively on the rate of change of uranium to lead, of rubidium 87 to strontium 87, and of potassium 40 to argon 40—we find that the time that has elapsed since they were last heated to high temperatures is about 4.5 eons. It is probable that the moon, the earth, and in fact the entire solar system were formed at that time. Any theory of these events must explain the curious physical structures and chemical composition of these meteorites.

It is most curious that the cosmic-ray ages of stone meteorites are only some tens of millions of years, and no certain explanation of this observation is available. However, objects moving in the neighborhood of the earth's orbit would be expected to exist in free space for about this length of time before they collide with the earth. Thus for most of geologic time they must have been covered with a layer of screening material, about a meter in thickness, which prevented the cosmic rays from producing special varieties of atoms, in this case the inert gases helium 3, neon 21, and argon 38. They were broken out of this environment as objects so small that cosmic rays could penetrate them. This requirement demands that their diameters should be in the range 30 to 100 cm. Thereafter they traveled in interplanetary space for some tens of millions of years. Could they have been blasted off the moon by the heads of comets? This is a possibility, and if it were so we would know of what some parts of the lunar surface are composed. However, only the transport of some pieces of the moon's surface to the earth can decide whether this supposition is correct.

We may conclude that the moon's surface was fashioned mostly by great collisions with its surface some 4.5 eons ago during a relatively short period of time—probably less than a million years. Since then it has been bombarded by lesser objects which have produced mostly smaller craters.

THE OTHER HEMISPHERE OF THE MOON

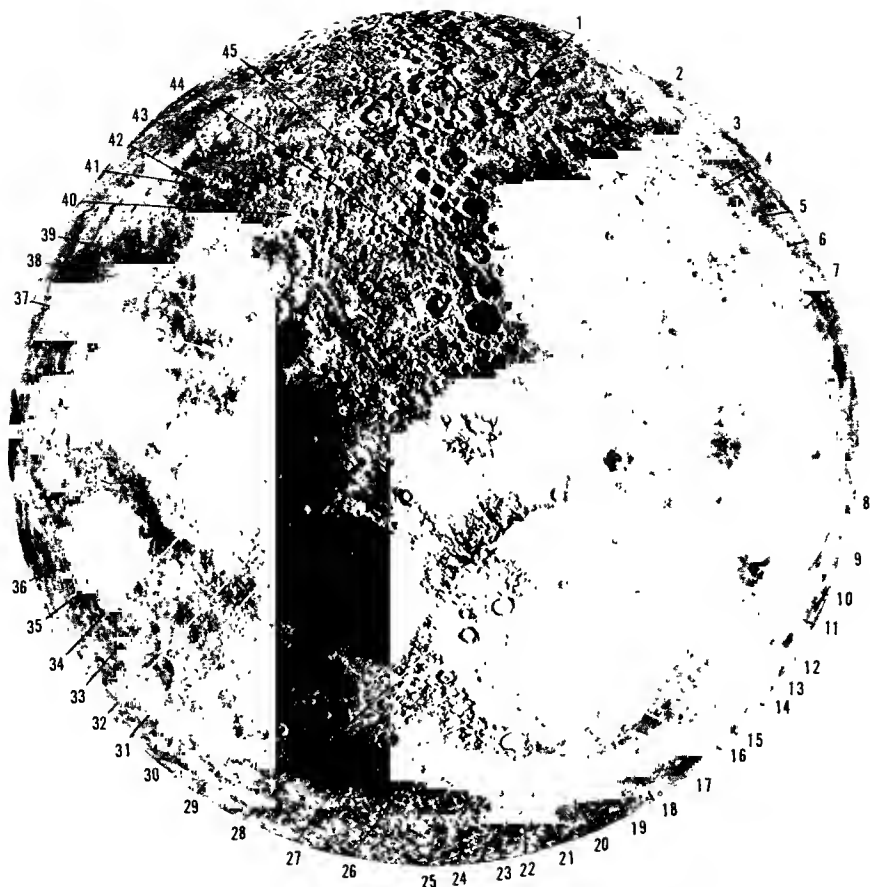
The great space vehicles of the Soviet Union have given us a glimpse of the previously unknown hemisphere of the moon: this feat must be rated as the greatest exploration since the discovery of America by Christopher Columbus. This first observation (pl. 5) gives us only a vague idea of what the "other side" is like and what we may learn from it. It has fewer maria than the visible hemisphere; this is unexpected but not surprising, because the Imbrian collision has supplied so many gray smooth areas to this side, that is to say its own area and probably much of Oceanus Procellarum, Mare Nubium, and other neighboring areas. If by chance the planetesimal had fallen on the other side of the moon the general appear-

ance of the two hemispheres would have been largely reversed. Certainly removing Maria Imbrium and Serenitatis would produce this general effect. The number of craters on this side is so great that it would not be possible by any stretch of the imagination to suppose that the great "land" areas of the other side would not be covered by similar craters. Though we might suppose that an equivalent of Mare Imbrium would be found on the far hemisphere, it would not be surprising if this did not occur.

On the basis of pictures so far made available to the West by the scientists of the Soviet Union we are not able to draw any very important conclusions about the structure and history of the moon. The maria on the limb of the moon extend to the other side, and Mare Moskva (Moscow Sea) occupies the approximate middle of the further hemisphere. Again there is an indication that it has a neighboring smooth area which might be due to a flow of lava from the area of a collision or to the fall of dust and rubble produced by such a collision. It is quite evident that general erosional effects from sunlight and particle radiation from the sun have not been very effective in shaping the moon's features.

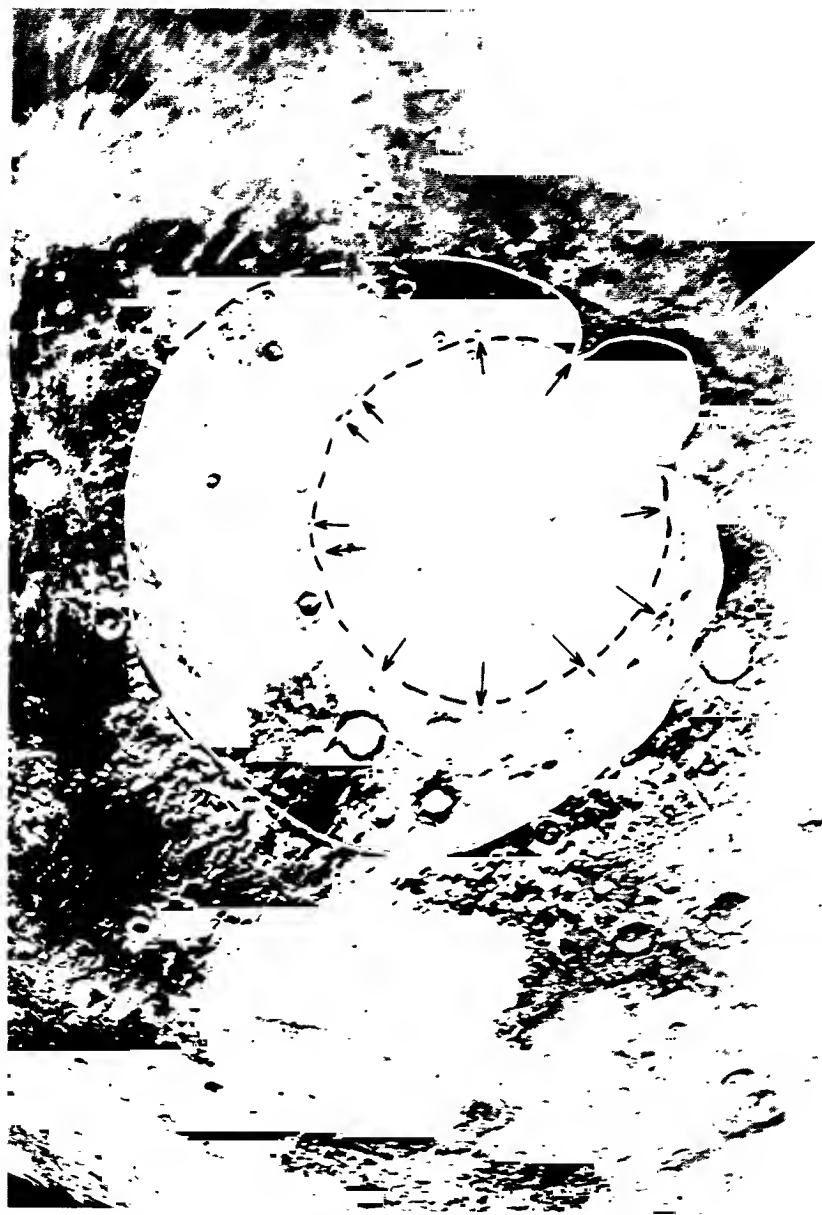
OTHER FEATURES OF THE LUNAR SURFACE

Over the years, many features of the lunar surface have been recorded in considerable detail by many observers, and some new details have been added by recent observations. The rays from some of the craters cross all other features, both the mountainous and depressed areas. They are due undoubtedly to particles thrown out over the surface as a result of the explosive collisions which produced the craters. In the high vacuum existing on the moon's surface, each dust particle would travel in an elliptical path, and if the particles from a crater moved in similar but not identical paths, they would fall in a pattern which might or might not be that of the observed rays. If such particles were moving with a velocity of 1.7 km. per second or greater, and if the initial direction were parallel to the lunar surface, they could travel completely round the moon and arrive back at their starting point in somewhat more than 108 minutes. The moon in this time would have rotated to the west, and the particles would, therefore, miss the original crater and fall on its eastern rim, if the orbit were in a north-south direction. Two rays of Tycho do just this. It has recently been suggested that, if particles were thrown vertically to a great height and fell back to the surface in about the same length of time, the same displacement would be observed. The rays of Copernicus are very irregular, and various explanations have been given of this. Possibly a slight atmosphere was present at the time when they were formed. Many well-formed



The moon. The mountains formed by the spray of material from the Imbrian collision can be seen in this picture. (Lick Observatory photograph)

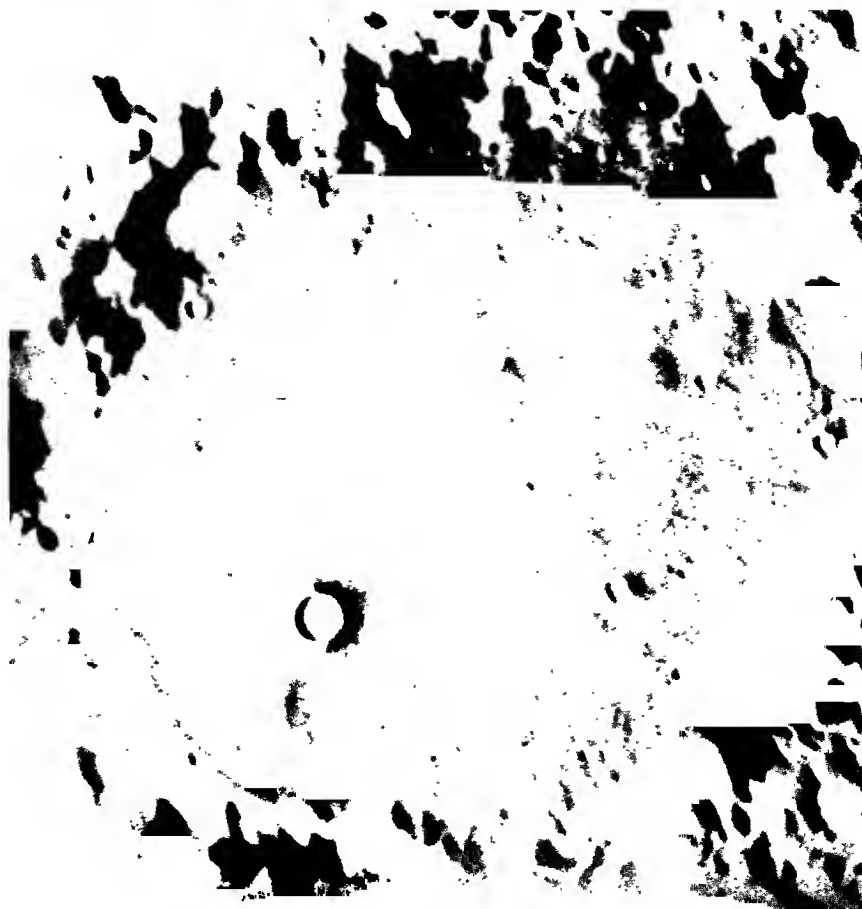
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|--------------------------|------------------------|--------------------------|
| 1. Tycho | 16. Sinus Iridum | 31. Julius Caesar |
| 2. Weiss | 17. Jura Mountains | 32. Maclear |
| 3. Mare Nubium | 18. Laplace | 33. Mare Tranquillitatis |
| 4. Hippalus | 19. Strahl Range | 34. Palus Somni |
| 5. Mare Humorum | 20. Spitzbergen | 35. Proclus |
| 6. Ptolemaeus | 21. Pico | 36. Mare Crisium |
| 7. Flamsteed | 22. Plato | 37. Capella |
| 8. Oceanus Procellarum | 23. Apennines | 38. Theophilus |
| 9. Copernicus | 24. Pion | 39. Mare Nectaris |
| 10. Aristarchus | 25. Aristillus | 40. Altai Mountains |
| 11. Prinz | 26. Alps | 41. Piccolomini |
| 12. Carpathian Mountains | 27. Caucasus Mountains | 42. Borda Valley |
| 13. Archimedes | 28. Autolycus | 43. Rheita Valley |
| 14. Mare Imbrium | 29. Mare Serenitatis | 44. Alphonsus |
| 15. Heraclides | 30. Haemus Mountains | 45. Arzachel |



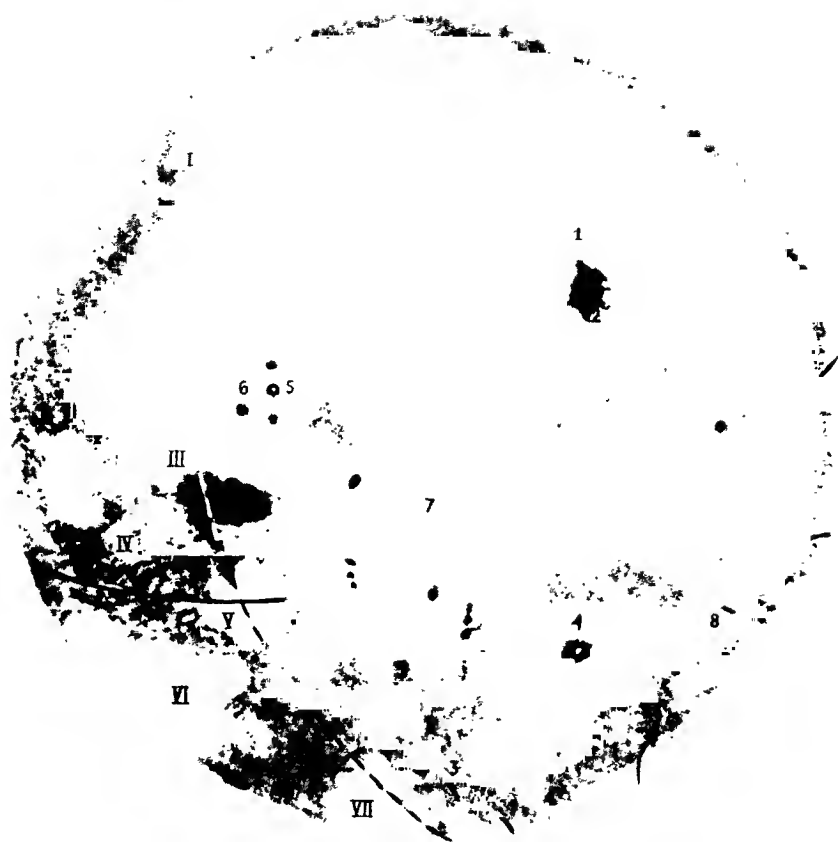
Mare Imbrium, with foreshortening eliminated. Mare Imbrium is outlined by the solid curve. Sinus Iridum is the bay at the lower right. The arrows indicate mountainous masses just outside the collision area. Three of these arrows point to masses not visible in this picture but easily seen in other photographs of this area (see also page 10).



Maria Imbrium and Serenitatis, showing the orientated mountain structures radiating from the collision area in Mare Imbrium. These structures show that the Imbrian collision occurred after the collision that produced Mare Serenitatis. (Mount Wilson and Mount Palomar photographs.)



Ptolemaeus, showing the many small craters. The surface is not smooth, and the smooth gray material covers some craters which antedated the formation of the material which covers the floor. The walls have been scarred by projectiles which arrived from the north-northeast and which were part of the debris from the Imbrian collision



The other side of the moon as seen from Lunik-3. The dotted line shows the edge of the visible part of the moon. All features to the right of that dotted line are invisible from the earth. Features marked on the visible section are (I) Humboldt Sea, (II) Sea of Crisis, (III) Regional Sea, (IV) Sea of Waves, (V) Smith Sea, (VI) Sea of Fertility, (VII) South Sea. Newly seen features: (1) Moscow Sea, about 300 km. across, (2) Bay of Astronauts, (3) the hitherto unknown section of the South Sea, (4) Tsiolkovsky crater with its central peak, (5) Lomonosov Crater with its central peak, (6) Joliot-Curie Crater, (7) Soviet Mountain range, (8) Sea of Dreams. (Photograph courtesy Pix Inc., New York)

craters have no rays: possibly they are older and the rays have become obliterated by the fall of micrometeorites, or perhaps, again, the moon had a temporary atmosphere when they were formed. Proclus has rays extending in all directions except toward the southeast: Fielder has reported the presence of a ridge there which may have intercepted the particles. If this is the correct interpretation, we can conclude that the collision sprayed out this material in a horizontal direction. Chemical effects such as the escape of gases from below the surface may also have been important in producing this unsymmetrical ray pattern.

N. Kozyrev [8] has reported that, during November 1958, gases escaped from the region of the central peak of Alphonsus, and he published a spectrum of these gases. He states that the original spectrum shows the presence of the C_2 bands which are prominent features of comet spectra. No change in the appearance of the central peak has been noted, and thus this could not have been a typical volcanic eruption such as is observed on the earth; possibly it was an eruption of water from the interior. Many small black areas have been observed in various parts of the moon, and in fact several examples appear in Alphonsus. Often they have small craters in their centers and look as though gaseous eruptions of some kind had occurred. If C_2 —or rather, compounds which the solar light dissociates to give C_2 —escapes from the moon, some blackening of the surface by graphite should occur.

A very curious and puzzling feature of the surfaces of the maria are the great sinuous wrinkles some 100 meters high, some kilometers wide, and hundreds of kilometers long. G. P. Kuiper [9] has recently reported that there are often cracks along their tops, and in some cases white material can be seen in these cracks. Does the white material consist of encrustations of salt, possibly deposited by escaping water? J. W. Salisbury [10] has made an interesting suggestion in regard to some rounded hills that have been observed for many years. He suggests that water has caused hydration of olivine present in these regions, causing it to swell and elevate the surface. Possibly the wrinkles in the maria overlay cracks below, through which water rises from the interior. The wrinkles look much like sand dunes or slides of some kind. Their origin is uncertain, but probably they are superficial in origin, and the unraveling of the puzzle will contribute little toward a fundamental understanding of the moon.

Long cracks occur in various regions of the moon, and in some places craters are distributed along them. The curious distribution of the craters along these cracks shows that they are certainly not due to collisions. They are due to the escape of gases from the interior, and have long been interpreted in this way. An outstanding example lies just

west of Copernicus, but others exist in the land areas and in the regions near the center of the moon's disk. These cracks are probably due to some general phenomenon, such as a gradual expansion of the moon due to increasing temperature; the escape of gases may well be due to this same circumstance.

The big valleys have not yet been discussed. The Alpine Valley is the most prominent of these and is about 130 km. long. It points in the direction of the great collision in Mare Imbrium and has been ascribed to the effects of an iron-nickel object plowing through the surface. It has also been suggested that it is due to a crack in the lunar surface. It is certainly much straighter than the other features, which all agree are cracks. The Rheita and Borda Valleys in the southwest regions are even longer. All are remarkably straight; if they are in fact cracks plowed out by iron-nickel objects it is evident that these were very large and were moving with high velocity.

SOME PROBLEMS OF LUNAR EXPLORATION

On all grounds, the most immediate task of lunar exploration should be to determine the composition and physical character of the maria. Quite simple observations on a few samples of material by methods that permit the study of the crystalline structure would unequivocally answer questions raised in this paper. Such observations cannot be made from a distance of 384,000 km.: obtaining better photographs that will resolve smaller craters will give but little additional information. The color of the rocks is determined by their composition and by the action of ultraviolet and particle radiation in a near-perfect vacuum during the last 4.5 eons.

Radioactivity could be measured from a space vehicle flying some hundreds of kilometers above the surface. If the radioactivity is similar to that of the earth, much differentiation of the lunar surface by melting processes must have occurred. If the concentration of radioactive elements is low, we must conclude that the composition is similar to that of meteorites and that little differentiation has occurred. The former result would mean that the moon has had a very high-temperature history, and the latter that it has had a low-temperature history.

The moon's density is less than that of the earth, even when allowance is made for the compression in the latter due to its great interior pressures. This means that the moon contains less iron than the earth or more low-density substances, most probably water. If the reason is more water, this would be expected to be concentrated in the surface rocks as water of crystallization, and the percentages required are large—probably 10 percent or more. This could be detected easily if simple chemical analyses could be made. If the reason for the low

density is lack of iron, this would indicate that the moon has a composition similar to that of the sun, and that the earth and the other planets acquired increased amounts of iron during their formation. This bears on two important problems, namely, the origin of the elements and the origin of the solar system.

The rigidity could be determined by seismographs and gravimeters placed on the surface, and these could be flown to and landed on the moon. Such measurements will show whether the moon is now molten in the deep interior and give much information about its internal temperature.

The determination of the age of the moon's surface, by radioactive dating methods, will tell us definitely the time at which the events described in this paper occurred. The surface materials—particularly at the poles, which have remained cool during geologic time—will give us a record of cosmic-ray intensities during the time that the solar system has existed. For such studies it is necessary to extract the inert gases from the surface materials. Knowing how rapidly they are produced by cosmic rays, we can calculate the time of exposure if the intensity of the rays has been constant. If the age so calculated agrees with the radioactive ages, we should then know that the cosmic rays have been constant in intensity, at least on the average. Disagreement would require another explanation.

The moon has been an object for astronomical study for centuries. We are now entering a period when physical and chemical studies will supplement the astronomical ones. Certainly the petrologists will have a field day if at some time samples of the moon can be secured. However, if the story of the moon as presented here is correct, the usual processes of geology—the mountain uplift, volcanology, erosion, sedimentation, and formation of the fossil record—will have little application to selenology.

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Exploring the Solar System by Radar¹

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[With 3 plates]

ASK the average person about exploitation of the solar system, and he will probably give you an image of giant rockets firing complicated instruments into space. Or perhaps he will remind you of the richly detailed picture built up over the centuries from optical studies and added to during the last few years by infrared and radio observations. It may not occur to him, however, that radar techniques are beginning to play an important role, too.

Radar is, in a sense, simply two-way radio. Some sort of signal is emitted by a directive antenna on the earth, travels to the object being studied, is reflected in many directions, and a tiny remnant of it eventually arrives back at the earth to be collected by the same antenna. Since we know exactly what the transmitted signal is, we can compare the returned echo with what was transmitted, so as to test something about the target body, perhaps something that would be difficult to isolate and study in any other way.

One of the simplest examples of such a test is the measurement of distance. If the experimenter knows the speed at which energy travels, he can determine the target's distance just by measuring the elapsed time between transmission and reception—a much more direct and usually more accurate method than the optical use of trigonometric parallax. (Time measurements to one part in a billion are common with today's electronic equipment.) But, as we hope to show here, many more things than this have been done, and still more will assuredly be done in the next few years.

The first radars were not military devices at all, but instruments used to probe the structure of the ionosphere by vertical soundings. These date back to 1926, 6 years before K. G. Jansky made his first

¹ Reprinted by permission from *Sky and Telescope*, vol. 20, No. 2, July 1960.

² Operated with support from the U.S. Army, Navy, and Air Force.

radio astronomy discoveries. In this article we shall omit the fascinating story of radar studies of the ionosphere, of meteor trails and aurorae, and concentrate on extraterrestrial objects, such as the moon, planets, sun, and the tenuous contents of interplanetary space.

Radar came dramatically to the attention of astronomers in 1946, when war-developed equipment proved capable of bouncing an echo off the moon, 240,000 miles away. For the next 12 years, the story of radar astronomy was that of moon echoes. Over that entire period, rapid improvements were being made in radar technology, yet these were still not sufficient to permit detection of the next most distant target, Venus.

Then, within a year of the March 1959 announcement of successful contact with Venus, by a group under Robert Price at Lincoln Laboratory, there came the news that V. R. Eshleman's team at Stanford University had detected solar echoes (February 1960). And there is talk that radar contact with Mars may be attempted during its opposition in December 1960, or at the February 1963 opposition. Why so much sudden activity after a 12-year interval when only the moon was observable?

THE EFFECT OF DISTANCE

The reasons are clear when one appreciates the important role that distance plays in a radar detection. Venus at inferior conjunction is some 100 times more distant than the moon, whereas Mars at closest opposition is only $1\frac{1}{2}$ times as distant as Venus, and the sun $3\frac{1}{2}$ times. In a one-way transmission, the energy received is proportional to the inverse square of the distance; however, with radar the energy must not only reach the target but be propagated back again, suffering another inverse-square attenuation. The result is a received signal energy proportional to the inverse fourth power of distance. Venus has a diameter a little over $3\frac{1}{2}$ times that of the moon, and thus roughly 10 times the reflecting area. But its 100-fold greater distance means that the energy returned is $10/(100)^4$ or 10^{-7} that from the moon, if for both bodies the power reflected is proportional to area.

Making the same calculation for each of the planets, and plotting their detectability relative to the moon's, we get the pattern of points in figure 1. Several satellites and minor planets are also included. Clearly, after we have bridged the gap of 10^7 in detectability from the moon to Venus, there are many radar targets in close succession.

Another increase in 10^7 in radar performance beyond that needed to detect Venus would encompass all the planets except Pluto—provided detectability depended only upon the diameter of the body and its distance from earth. Unfortunately, matters are not this simple. Discrepancies of several orders of magnitude from the numbers given in figure 1 are possible, owing to different reflectivities of the planets'

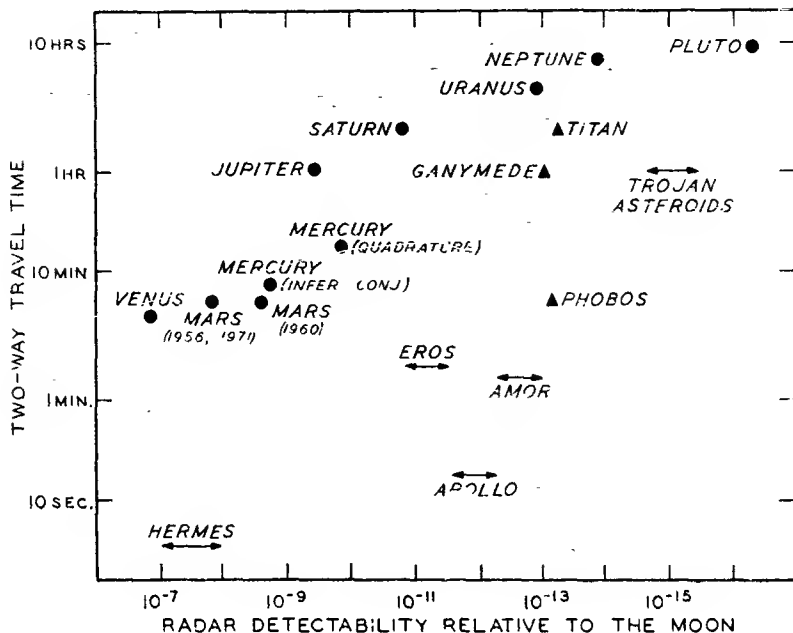


FIGURE 1.—For the planets, a few satellites, and some asteroids, the radar detectabilities are compared with that of the moon. These results have been deduced only from sizes and relative distances, without regard to possible differences in surface reflectivity. For the asteroids, approximations are given, since their sizes are uncertain. All illustrations with this article are from MIT's Lincoln Laboratory, unless otherwise credited.

surfaces or the absorptivities of their surrounding atmospheres. As a matter of fact, the observed strength of the return signal can indicate the reflectivity of a planet, since the diameter and distance are already known.

RADAR TO THE MOON

The first echoes whose characteristic delay time and Doppler frequency shift positively identified them as reflections from the moon were obtained by the U.S. Army Signal Corps in 1946. But it was puzzling that lunar echoes were not always observed even though conditions appeared to be favorable. Some hitherto unsuspected effect must have been taking place.

Australian and British scientists showed that the observed fading had two causes. A relatively rapid component stemmed from changing interference among simultaneous reflections from different regions of the lunar surface, as changing librations caused it to turn under the radar beam. And a propagation effect, Faraday rotation, was responsible for the slow fading which caused the signal to disappear for

minutes at a time. This effect occurs when a wave passes through a region like the earth's ionosphere with a magnetic field present. Under certain conditions, the plane of polarization of the radar signal was being sufficiently twisted, as it passed twice through the ionosphere, that it arrived back at the receiving antenna in a cross-polarized orientation, producing zero output.

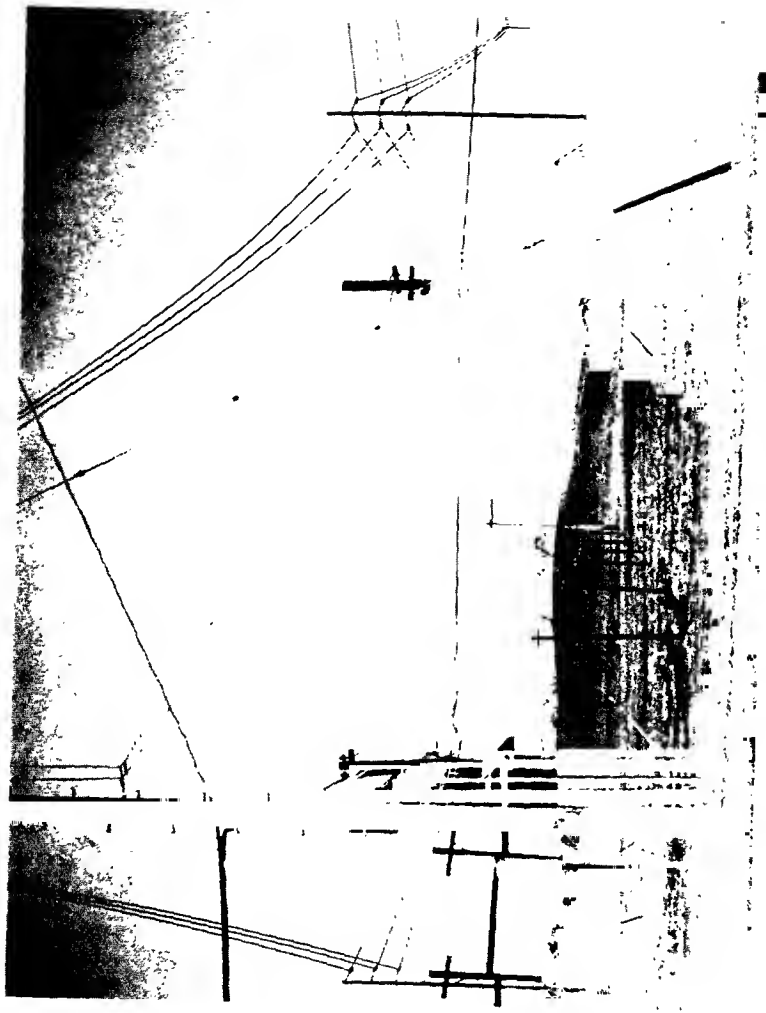
By unraveling the sources of the fading, it became possible to eliminate the ionospheric effects (through the use of circularly polarized transmissions, for instance), in order to study more directly the reflective properties of the lunar surface. In addition, the Faraday rotation could also be employed as a new tool to probe the properties of the terrestrial ionosphere.

An unexpected property of lunar reflections at radio wavelengths came to light with the discovery, by J. H. Trexler at the Naval Research Laboratory, that when a short pulse was sent out, most of the returned signal power was confined to an interval of a few hundred microseconds. So brief an echo could have been produced only by a lunar terrain having relatively gentle slopes, as contrasted to the precipitous and craggy surface shown in popular illustrations. Further verification was soon provided by accurate measurements of the travel time, proving that the sharp echo originated in the nearest region of the moon.

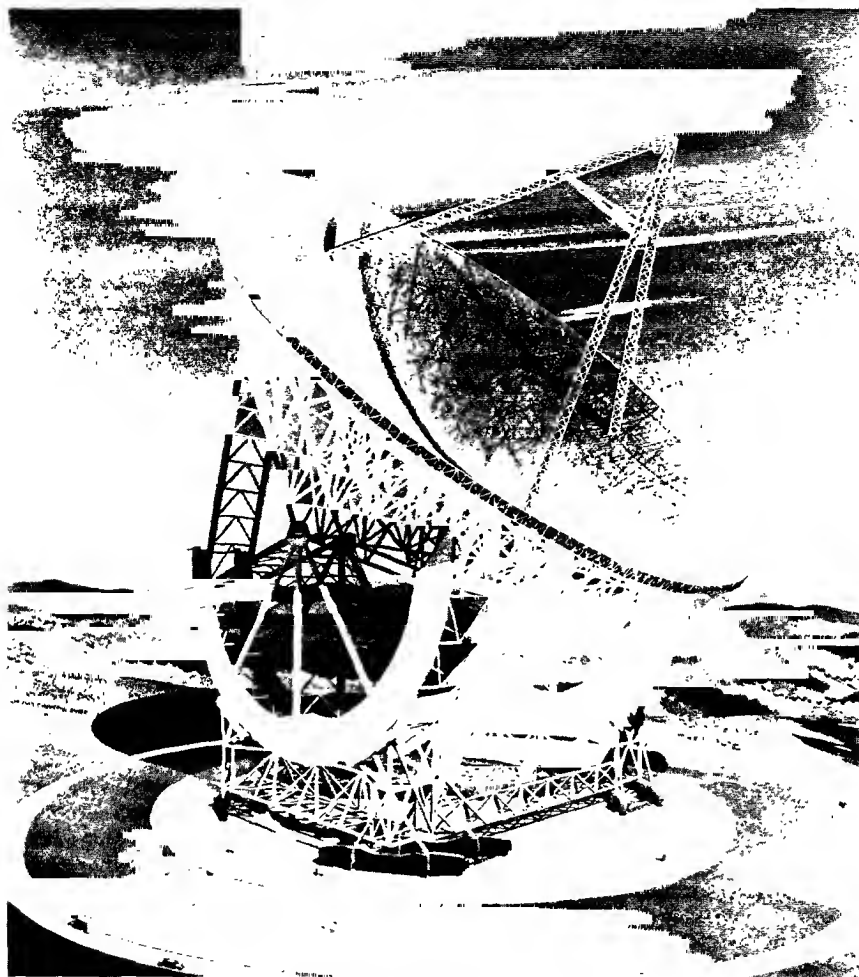
It had long been known that at optical wavelengths the disk of the full moon exhibits a striking uniformity in apparent brightness from center to edge. The radar work made it clear that the nature of scattering from the moon's surface was distinctly different when measured with wavelengths of tens of centimeters instead of tenths of microns. Unlike its visual appearance, the moon at radar wavelengths has a strong highlight in the center.

As radar transmitters became more powerful and antennas larger, the echoes received back from the moon stood higher and higher above the receiver noise level. Within the past few years, sufficient signal has become available at several stations to show that there is in fact observable echo power all the way out to the lunar limb. Figure 2 shows the results of one such recent measurement. In addition to the highlight or specular component, there is a diffuse contribution which very nearly obeys a Lambert scattering law. A reasonable fraction of the moon's surface, therefore, must have irregularities that are comparable in size to radar wavelengths—a conclusion of some importance to those who may wish to land there.

How can we learn where these rough portions are? Photographs, of course, tell quite a bit about the topography, and measurements of the lengths of shadows cast by objects on the moon's surface have given us much information about the height scale of its gross features. The



A part of Stanford University's antenna used for the first successful radar observations of the sun. It is designed especially for operation at the low frequencies required for obtaining echoes from the solar corona. Each side-by-side rhombic antennas make up the array, one and part of a second being seen here. (Stanford University photograph.)



An artist's conception of the 600-foot antenna under construction for the U.S. Navy at Sugar Grove, West Virginia. This huge steerable paraboloid will be precise enough to work at wavelengths as short as the neutral hydrogen line at 21 centimeters. It will be an important tool for future planetary radar experiments. The installation, known as the Naval Radio Research Station, is to cost about \$80,000,000. (U.S. Navy photograph.)



1. This small crystal forms the heart of the maser built by Robert H. Kingston for amplifying radar echoes from Venus. The paramagnetic crystal accepts power delivered at 5,400 megacycles through the entry at the right, and uses it to augment the weak 440-megacycle signal that flows in the loop of wire around the crystal.



2. The CG-24 computer seen here works directly from the output of the Millstone Hill radar in tracking artificial satellites, and to sum up Venus echoes. It was used to make the lunar map in figure 4.

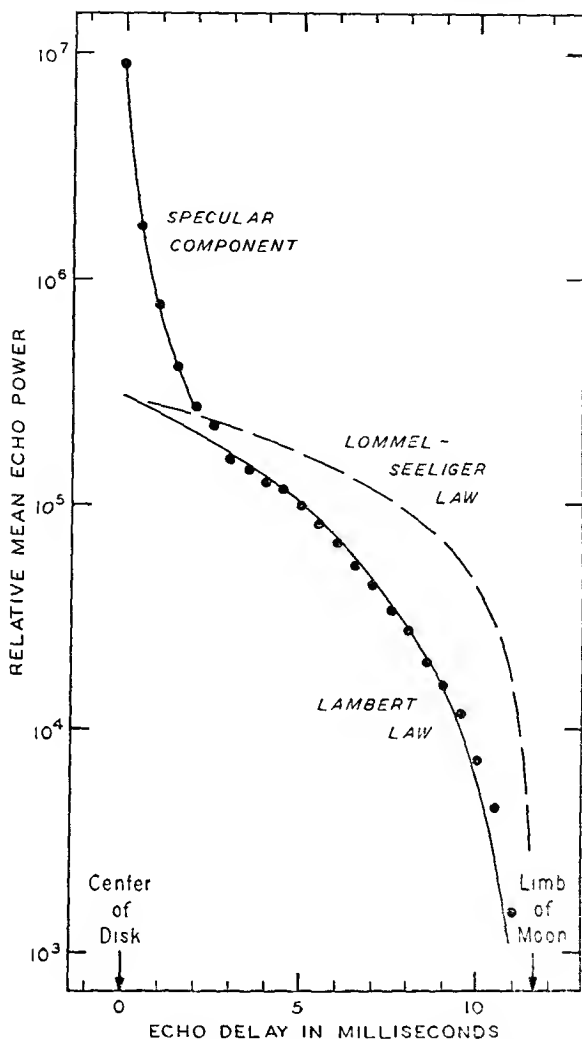


FIGURE 2.—Gordon H. Pettengill's observations of the radar brightness of the moon's disk at various distances from its center are shown by dots, each representing the sum of 24,000 pulses. At the frequency used, 440 megacycles per second, the outer portions of the moon scatter in accordance with Lambert's law, and not the Lommel-Seeliger law, which fits optical measurements better. Near its center, the lunar disk is much brighter by radar than Lambert's law predicts. At Stanford University, similar studies have been made.

distribution of radio energy reflected from various parts of the disk would help fill remaining gaps in our understanding. If we had sufficiently narrow beam widths, a radar "picture" of the moon could be taken by simply scanning across its disk. However, another approach that does not require resolution in angle has recently shown promise.

MAPPING THE MOON BY RADAR

Suppose a pulse of radar energy reflected from the moon is observed. The echo will have a longer duration than the original pulse, because the reflection from the edge of the moon reaches us later than that from the center of the disk. Hence, by selecting a part of the returning signal within a limited time interval, we know that we are observing a ring-shaped portion of the disk, centered on its midpoint. But how do we isolate the energy reflected from a particular part of this ring?

To achieve this, advantage is taken of the changing libration of the moon, which causes a slow apparent turning of the moon as seen by a terrestrial observer. At any moment, half of the moon's face is approaching us and half receding, with respect to the center of the disk. Thus the frequency of the energy returned from the ring differs from point to point, in a predictable way, because of the Doppler effect. Figure 3 shows the relation between range and frequency for a turning spherical body such as the moon.

If we could arrange to measure simultaneously both range and frequency with sufficient precision, some semblance of a map could be prepared. The separation of returns from different parts of the lunar surface is possible because the energy received at a given range and given frequency must have been reflected only from two definite points on the moon. Techniques which have been available for years give adequate accuracy in range. The frequency measurement, on the other hand, calls for a new level of stability, several parts in 10^{11} over the observing interval of 2.5 seconds, if useful resolution is to be achieved.

This stability has recently been obtained, and figure 4 shows some experimental results gathered by this technique. It is hoped that a number of these measurements will make it possible to match the observed spectra with specific parts of the lunar disk, and build up a picture of the moon in terms of radar reflectivity.

The span of frequencies covered by the echo is determined by the product of the target's radius and turning rate. Also, the total time duration of the echo is a direct measure of the radius. Hence, the rotational rate of a planet may be found by radar. Such a study of Venus would be very important, since the length of that planet's day is still unknown. Perhaps the most interesting property of these methods is that angular resolution is not required. As radar capability improves, Venus and Mars may be studied in detail with good surface resolution, without recourse to impossibly small antenna beam widths.

FUTURE TECHNIQUES AND EQUIPMENT

The application of these methods to very distant targets will require continuing efforts in four major areas: Transmitters, antennas, low-

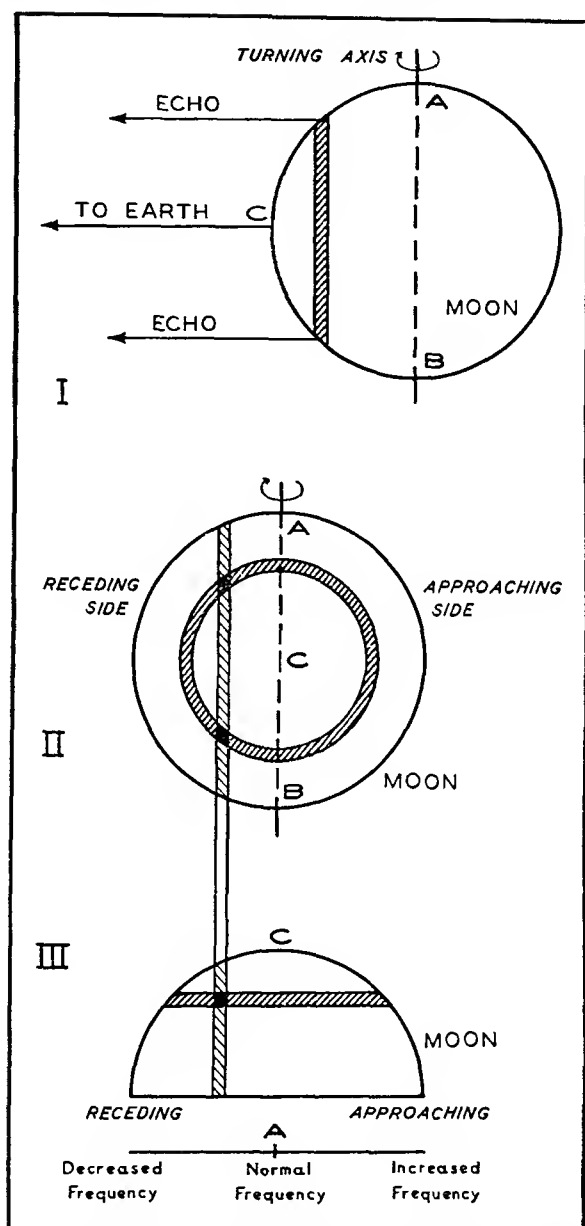


FIGURE 3.—Mapping the moon by radar. In diagram I, by selecting that part of the echo within a limited interval in range, we observe only the shaded area, a ring on the moon as seen from the earth in II. C is the center of the disk, and AB is the axis around which the moon appears to turn, because of changing libration. Here AB has been arbitrarily drawn perpendicular to the line of sight. Half of the turning disk is approaching, half receding. By further selecting a limited frequency interval, we observe only the narrow strip of disk between the vertical lines. In III, looking down on the moon, we see one of two small areas thus isolated by the combined selection of range and frequency. Compare III with the observational record in figure 4.

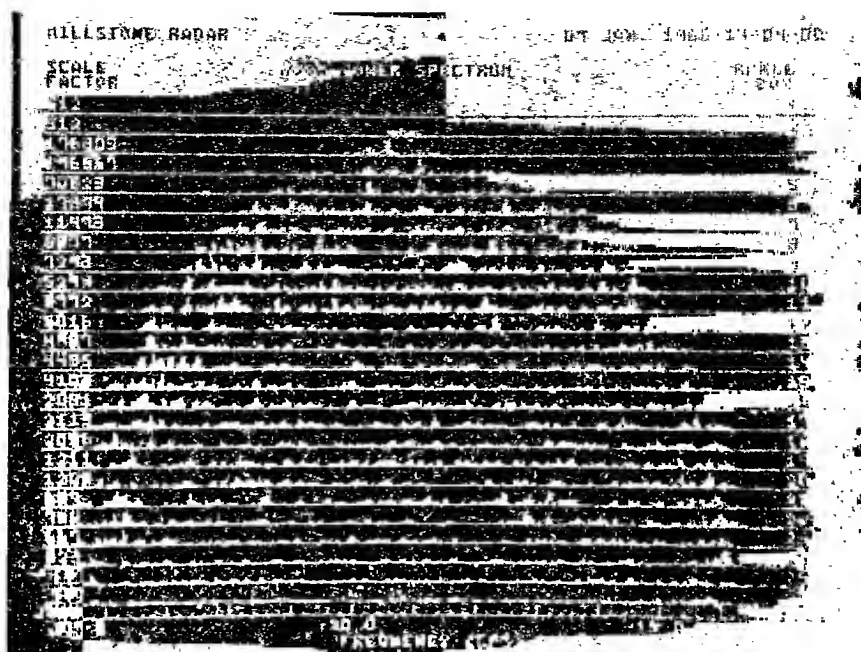


FIGURE 4.—This preliminary radar map of the moon is from 440-megacycle observations with the 84-foot Millstone Hill antenna on January 8, 1960, at 0:04 Universal time. The sharp semicircular boundary corresponds to the moon's edge seen from above (as in III of fig. 3), the part of the moon nearest the earth being at the top of the map. The range increases downward by steps of 0.0005 second of radar echo time per line. Since the echoes from the center of the moon as we see it are enormously stronger than the limb echoes (bottom), the signal strengths have been scaled down by the factors labeled at the left.

noise receivers, and signal-processing techniques. The average power available at frequencies extending from 30 megacycles per second to 30,000 megacycles must be increased. In many cases, the radio power available at present is already crowding the capacity of a single transmission line. New methods are needed to generate and distribute the power over the antenna surface without having to funnel it all through one transmission line. In order to preserve complete knowledge of the transmitted waveform, these new transmitters must not distort the output, even at the highest frequencies and powers that may be used.

Perhaps the most important field for improvement is antenna capability. In radar systems, the antenna plays a dual role, contributing to the outgoing "power-on-target," and also determining the amount of scattered signal that may be gathered into the receiver. At the present time, antenna designs so nearly achieve full theoretical efficiency, for a given size and operating frequency, that little remains but to increase the collecting area if more sensitivity is to be realized. Certainly the current trend lies in that direction. An example of the

approach that has been used at relatively low frequencies (30–60 megacycles) is the Stanford solar radar installation, shown in plate 1.

For the major part of the spectrum available to radar astronomy (substantially the same region of interest in radio astronomy), however, the choice seems to favor a parabolic reflector illuminated by a relatively simple antenna located at its focus. An instance of a very large paraboloid under construction is seen in plate 2.

To a certain extent, the value of an antenna of given size may be improved by operation at a higher frequency (shorter wavelength). As the wavelength is shortened, the reflecting paraboloid forms a narrower beam, concentrating more of the transmitted energy on the target. But the dimensional accuracy of the antenna and its mount must be proportionately greater. Furthermore, above 10,000 megacycles absorption in the earth's lower atmosphere becomes important. And in some cases, as the sun, the reflection properties of the target tend to place an upper limit on useful frequencies.

Although much work may be carried on with the simple displays that conventional radars use—such as oscilloscopes and cameras—a digital computer of some sort is required for more advanced signal processing. When the signal-to-noise ratio of the desired return falls below unity, special processing is necessary to extend the detection sensitivity. But even where sufficient signal is available, computers are needed if techniques such as those described for lunar mapping are to be attempted.

Finally, a continued effort is required to reduce receiver noise temperatures, a problem discussed by F. D. Drake in *Sky and Telescope* for December 1959, page 87. Masers and variable-reactance amplifiers appear promising, and in the future may be improved so much that the residual noise level will be limited only by the background temperature of the sky or, sometimes, the target. This theoretical limit is already near at hand in some cases, although the availability of reliable amplifiers using these principles at all interesting frequencies is still limited.

THE VENUS EXPERIMENTS

Initial astronomical use of such a device came in February 1958, when Lincoln Laboratory employed a 440-megacycle solid-state maser (pl. 3, fig. 1) in its first Venus observations, described on page 384 of the May 1959 issue of *Sky and Telescope*. When the experiment was repeated, at the next inferior conjunction in September 1959, a parametric amplifier was used. In both cases the background noise at the receiver input was kept down to 170° Kelvin.

The 440-megacycle transmitter sent a sequence of several thousand pulses, each 0.002 second long and several hundred kilowatts in peak power, into the 84-foot Millstone Hill antenna dish, which was pointed

at Venus. The pulse sequence lasted for the entire 5-minute round-trip travel time, so the last pulse was transmitted just before the echo of the first was due. Then the antenna output was switched over to feed the low-noise receiver, whose output was recorded on tape and later processed in a digital computer. Each such 10-minute operation constituted a "run."

The processing had two purposes. First, the individual echoes were much too weak to be distinguished from the background noise, so it was necessary to add together all of the several thousand received echoes-plus-noise to build up the signal-to-noise ratio. Since the echoes have a more or less fixed structure, and the noise is different from pulse to pulse, the former add up faster than the noise.

A second function of the signal-processing equipment was to determine the correct value of the planet's distance. The transmitted sequence of pulses was deliberately made nonperiodic, since otherwise it would be impossible to tell which received pulse corresponded to a particular transmitted one. By matching up the outgoing and returning patterns, no ambiguities in time of travel will remain. This matching is too lengthy a job for the computer to do while the observations are in progress, so in the 1958 experiment the received signals were recorded for later treatment. In the second Venus experiment, a digital computer (pl. 3, fig. 2) located at the radar site was programed to do part of the processing during each actual run.

At the 1959 Venus conjunction, an experiment similar to this was carried out by J. V. Evans at Jodrell Bank in England. Our laboratory's 1958 work had produced four valid runs, of which two contained large-output signals agreeing in range. Since it was thought that the 25-million-mile distance to Venus had been measured to better than 250 miles, this implied that the solar parallax had been redetermined to within 1 part in 100,000. Over 150 runs were made during the 1959 Lincoln Laboratory effort, yet no echoes as strong as those of 1958 were observed, either in England or America, though the former group did get weak indications for a distance consistent with the solar parallax determined in the 1958 experiment.

It is difficult to explain the disparity between the results obtained at the two Venus conjunctions. Our current feeling is that the planet's reflectivity may be highly variable with time, and that the two successes in 1958 were observations made on very favorable occasions.

SOLAR SYSTEM DISTANCES

Astronomers, in specifying the mean distance of the earth from the sun, ordinarily speak of the corresponding solar parallax—the angular radius of the earth as seen from the center of the sun. Several proposed values of the solar parallax, with their probable errors, are

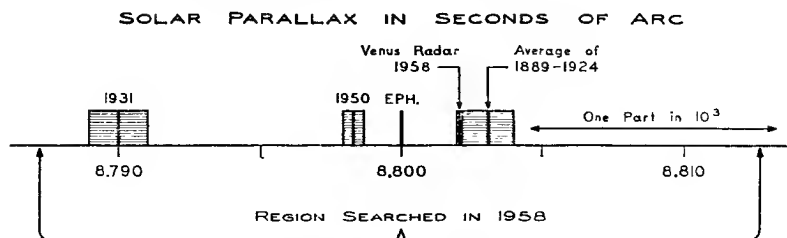


FIGURE 5.—Solar parallax is often used to specify the mean distance from the earth to the sun. Lincoln Laboratory's value from Venus radar experiments in 1958 is here compared with others, the probable errors being indicated by the shadings: 1931 Eros 0.001 second of arc; 1950 Eros, 0.0004; 1958 Venus, 0.0001; and 1889-1924 (seven determinations), 0.001 second.

compared in figure 5. H. Spencer Jones' 1931 result is from triangulation of Eros in that year; E. Rabe's 1950 determination is from perturbations of Eros, while the 1889-1924 figure is the average of seven optical methods. The value of 8.800 seconds of arc is not an observed but an adopted one, used in ephemerides. With these is compared the 1958 radar evaluation. The distressing thing about this compilation is the wide variance among the proposed numbers, with even the regions of probable error failing to overlap. It is hoped that additional radar observations will clear up the discordance.

But there is more to the story of interplanetary radar distance measurements than refining the value of the solar parallax. The method should ultimately allow the determination of the orbits of some planets to within a few miles. When this accuracy is attained, gravitational perturbations of higher order will have to be considered in interpreting what is observed. It should also be possible to study the relativistic motions of the perihelia of several other planets besides Mercury. Mars is especially attractive since it comes fairly near to us, has a rather eccentric orbit, and has an atmosphere whose retarding effect on the radar signal is probably negligible.

The effect of the intervening medium on the signal's speed of travel is important. By far the largest effect is caused by the dielectric constant differing slightly from unity, owing to free electrons in interplanetary space and in the ionospheres of the earth and the target planet. This retardation is greater at lower frequencies. For the 440-megacycle frequency used in the Venus experiment, it was calculated that a distance error of less than one part in a million would result from the combined effects of our ionosphere and an average of 1,000 electrons per cubic centimeter throughout the intervening space. Had the measurement been made at 50 megacycles, the corresponding discrepancy would have been 1 part in 60,000.

We can put this difference to work in studying the electron content

of space and in the neighborhood of the target. If a pair of radars operating at widely separated frequencies, such as 50 and 400 megacycles, can measure the travel time to distant bodies to 1 part in 60,000, and if the effect of the earth's ionosphere can be subtracted out, then the density of free electrons in interplanetary space could be deduced from the excess time of flight observed with the low-frequency radar over that of the high-frequency one. (Of course, this experiment would tell us only the total number of electrons between us and the planet, and in the absence of other data we could not say what fraction was in space and what fraction was in the vicinity of the planet.) Finally, knowing the total electron content, we could improve the original range measurement.

RADAR AND THE SUN

The procedure that was used to detect echoes from the sun's ionized corona is much like that employed for Venus, with two important differences. First, the sun itself generates so much radio noise that there is no particular point in working hard to minimize receiver noise. Second, the operation is at much lower frequencies, 20 to 50 megacycles being required. If higher frequencies are used, the signal penetrates so far into the corona before reflection that absorption losses become severe. At still lower frequencies, the signal is apt to be blocked by our own ionosphere.

In April 1959, the first successful solar radar experiment was carried out by researchers at Stanford University. (See p. 281 of the March 1960 issue of *Sky and Telescope*.) The strength of the echoes turned out to be in very close agreement with theoretical predictions published by the Australian radio astronomer F. J. Kerr in 1952. One important difference was that the returns appeared to come more or less uniformly from a wide range of depths in the corona. This might be expected if the coronal region had large irregularities.

The Stanford experiment used a high-power communications transmitter operating at 26 megacycles, feeding the array of eight rhombic antennas already partly shown in figure 5. The transmission consisted of a series of alternate 15-second on-and-off periods lasting for 15 minutes, approximately the time of flight to the sun and back. Again, a digital computer processed the received signal, so that the combined energy of all the individual returns could be used to enhance the final signal-to-noise ratio.

With the rapid progress of radar techniques, we may look forward to even more revealing radar studies of the sun over the next few years. Range-frequency maps of the corona, analogous to those already made for the moon, might unlock many secrets about the dynamics of the sun's outer envelope.

Even though some important things have been done, the history of radar astronomy has barely begun to unfold. As usual when a new tool becomes available, the most interesting results will be the ones we cannot foresee.

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Digital Computers: Their History, Operation, and Use

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INTRODUCTION

IN the past 15 years digital computers have emerged as an interesting and extremely useful tool not only for scientists but for workers in many other fields of human endeavor. Their use has been so widespread as to suggest that they may be the basis for another revolution comparable in significance to the industrial revolution. Their appeal and usefulness are due largely to the fact that they perform tasks which heretofore have required "intellectual" effort for their accomplishment. Much has been said about the ability of computers to perform in relatively short periods of time tasks which otherwise might require the brainpower of many humans working over long periods of time. Since computers do work which man normally does mentally, in contrast to doing jobs which require musclepower, there is some confusion and misconception about digital computers and their use. Man does not know nearly as much about intellectual activities as he does about physical. Further, he is less able to judge them by measures which are commonly understood.

First impressions of digital computers are impressive and perhaps confusing. Computers are expensive devices costing thousands or even millions of dollars. They consist of hundreds of thousands of electronic components interconnected in what appears to be a very complicated manner. Some of the equipment for putting information into or taking information out of computers is perhaps familiar, since commonly used electric typewriters and business accounting machines have been adapted for this purpose. However, much of the rest of the equipment is unfamiliar.

Digital computers are information-processing devices. The information is generally represented by numbers and the processing involves the performing of simple arithmetic operations such as adding, subtracting, multiplying, and dividing. Scientists use digital com-

puters for solving very complicated mathematical problems, and businessmen use them for the clerical operations associated with the processing of their data.

HISTORY

Mechanical aids to computation go back to the abacus, an ancient device still widely used in many parts of the world. The number representation system of a form of the abacus, with two beads above a bar and five below for each decimal digit, is now widely used in an electronic equivalent form, *biquinary*, in many modern computers. The adding machine was invented in 1642 by Blaise Pascal. This type of calculator was developed especially in the last century and is now widely used. Automatic multiplication and division by calculators was invented in 1902.

The man who had the original concept of what is now known as a digital computer was Charles Babbage, 1792–1871. Babbage was a professor of mathematics at Cambridge University but engaged in many activities outside the field of mathematics.¹ Babbage first conceived of a “difference engine” in 1822. This mechanical device would permit the automatic production of mathematical tables such as logarithms, sine, cosine, and other numerical functions. However, before he had completed this project he conceived of a much more general computing device called an “analytical engine.” It contained most of the concepts now considered to be essential in a digital computer. He drew up elaborate detailed drawings for the device. However, it was mechanical and required skills not then available. Only part of the machine was built; it is now in the British Science Museum.

Despite the fact that it was never built, the significance and implications of such a device were understood by a number of people at that time. Lady Ada Augustus Lovelace, 1815–52, daughter of Lord Byron, was quite familiar with the analytical engine and its potentialities. Much of what we know about the device is due to her writings on the subject.

About 100 years after Babbage, circumstances made it possible to build a digital computer. During World War II techniques were developed which were used for building the first electromechanical computers using electrical relays. Mark I was built at Harvard in 1944. Electronic techniques, however, permitted much higher rates of operation. The first electronic computer, ENIAC, was built at the University of Pennsylvania in 1946. It used 18,000 tubes, and with the unreliability of tubes at that time it was easy to “prove” that tubes

¹ As indicated in Bowden (see bibliography), Babbage invented the cowcatcher, the speedometer, suggested a fixed fee for posting letters, made an operations research analysis of the pin industry, was the first to sail across a railroad viaduct in a handcar, among other interesting activities.

would fail faster than they could be replaced. Nevertheless, this and many other problems were solved, and many thousands of computers have been built since then. It was 1950 before the first digital computer was built with all the characteristics now considered to be essential.

Interestingly, many of the devices adapted for use in computers have been available for some time. The basic bistable electronic circuit (the *flip-flop*) was invented in 1919. The equipment for input to and output from digital computers is adapted from communication and business-accounting devices. Punched paper tape was used by Samuel F. B. Morse, inventor of the telegraph. The familiar punched card was used by Jacquard in 1801 and is still in use to control weaving looms for making designs in cloth. (Babbage had intended to use punched cards in his analytical engine.) Hollerith adapted punched cards for the 1890 census, and many other uses have been made of them since then. And, finally, the mathematics needed for the logical design of digital computers was developed by another English mathematician of the last century, George Boole, 1815-64.

COMPUTERS VERSUS CALCULATORS

The solving of mathematical problems and processing of business data have been accomplished for some time by the use of manual calculators. How are computers different from calculators, which also do arithmetic operations? To answer this we must realize that doing the arithmetic operations is only part of the process of solving a problem when using a calculator. Deciding what numbers to put into the calculator, putting them into it, and after performing the arithmetic, deciding what to do with the numbers resulting from it and then doing it all involve more time than the arithmetic itself.

Computers differ from calculators in that computers do the *complete* job of solving a problem. They contain within themselves all the data pertinent to a problem and all the instructions for solving it, including alternate sets of instructions to be followed on the basis of decisions which the machine itself can make. Thus a digital computer is capable of completely solving a problem at electronic speeds without human intervention during the solution. However, the setting up of a computer to do this is frequently time consuming and expensive.

But what has a computer really gained over a calculator and its operator except speed? First, we must realize that for many purposes this speed advantage itself is sufficient gain. Being able to do hundreds of thousands or even millions of operations in the time formerly required for one is a tremendous advantage in solving a problem.

Ways for solving problems involving a very large number of operations have been known for many years, but the time and labor required

made them impracticable. For example, the value of pi can be calculated to any number of decimal places by several different formulas. William Shanks, 1812-82, an English mathematician, spent many years calculating the value of pi to 707 places. The results were published in 1854, and 92 years passed before a computer duplicated this remarkable feat.² Then in 1954 a computer calculated pi to over 3,000 places in 13 minutes computing time. At present it could be done in considerably less time. Incidentally, the method of calculation was the same as that used by Shanks.

There are many other problems that can be represented mathematically, the solution of which required a tremendously large number of operations. The solving of a large number of simultaneous linear equations is one example. Others are the "monte carlo" and relaxation methods of solving the intricate mathematics associated with atomic energy studies.

However, to answer the question above, digital computers do have advantages other than speed. They can perform *logical* operations as well as *arithmetic*. This is a very important property, which we will consider further after discussing some of the details of how a computer works and of the particular arithmetic of a computer.

HOW COMPUTERS WORK

Mechanical calculators use a system of motors, wheels, levers, dials, and other mechanical devices to perform the operations required of these calculators. The motor and wheels accomplish various numbers and types of mechanical operations, and the levers convey these operations to the dials for indicating the numbers. Each dial has 10 positions on it for the numbers 0 through 9.

Digital computers, on the other hand, are predominantly electronic rather than mechanical devices, but the electronic operations are analogous to many of the mechanical operations in calculators. Numbers are represented in computers by series of electrical pulses traveling from one part of the computer to another by wires. (These pulses are much like those produced in dialing a telephone.) They occur at such a high speed (hundreds of thousands or millions per second) that mechanical devices cannot be used to produce, control, or count them. Instead, electronic devices called *gates*, which use radio tubes or transistors, are used. Electronic *flip-flop* devices (devices which are in one condition or another, with no intermediate positions) also are widely used for counting pulses in computers. Many thousands of these gates and flip-flops may be used in any one computer.

² Shanks had verified his results to 500 places. The computer solution, however, showed that Shanks had erred so that his figures beyond the 527th place are incorrect.

To obtain the very high speed and extreme reliability required for accurately producing, controlling, and counting pulses, electronic engineers use devices which represent numbers not by a base of 10, but by a base of 2, that is, a binary system using only 0 and 1. Thus numbers are represented by combinations of many individual electronic devices, each of which are either on or off, or by pulses which are either present or absent at any given time. Many of these electronic devices have small neon lamps connected to them so that the lamps either glow or not depending on whether that device is representing a 1 or a 0. These lamps flash on and off quite rapidly as a computer operates and are frequently shown in movies or television views of computers. The binary system of representing numbers will be considered in detail later.

Since the numbers inside a computer are represented by electrical pulses sent from one part of the computer to another, the input and output devices for computers must operate in much the same manner. A common device for input and output for a computer is quite similar to a teletype machine. The numbers are represented by combinations of holes punched in a paper tape. As this tape is moved over a *reading* device, the presence or absence of holes in the tape produces a series of electrical pulses which the computer uses to represent the numbers. Similarly, a series of pulses in a computer can cause an output device to punch a series of holes in a paper tape. These pulses can also cause an electric typewriter to type the numbers in the usual form. This is desirable as the numbers are difficult to read as holes in a tape. Further, the typing of numbers on the keyboard of an input device will produce a punched paper tape suitable for input to the computer.

Many computers use business-accounting type machines for input and output. Numbers are represented by holes in the familiar punched card. However, the basic operation of these devices is essentially the same as considered above.

METHOD OF SOLVING PROBLEMS

An analogy can be used to illustrate the method by which a computer solves problems. Consider a room in which there is a large number of file cabinets, each file drawer marked by a number. Each drawer contains a slip of paper which is either a number or an instruction for some action to be taken. In this room is a clerk who goes to the first drawer and obeys the instruction he finds there. He will then go to the second drawer and obey the instruction there, and so on. The only exception to this sequence is when the instruction in a drawer specifically states that the next instruction is to be taken from some other storage location. The clerk, in obeying most of

the instructions, will have to refer to some other specified drawer for the data he needs to follow out the instruction. He also has a pad of paper on which to store temporarily the results of each operation he performs in obeying these instructions. Except for the first drawer, the clerk will not know in advance which drawers contain numbers and which contain instructions.

Yet by following the above procedure, which involves performing very simple operations at each step, it is possible for the clerk to solve a large number of problems including some of the most abstruse mathematical problems. The clerk will not need to know what he is doing or why.

As an example let us consider in detail how this technique can be used to calculate the value of a sum of money subject to compound interest. Assume that we wish to do this for just 20 periods of interest accumulation. Further assume that the file drawers (storage locations) are numbered 000, 001, 002, and so on. The clerk goes first to the first drawer (number 000) and finds there an instruction which says, "Take the number in drawer 020 and write it on the pad." The clerk then goes to drawer marked 020 and in it finds a number representing the initial value of principal. Having written this on the pad, he next goes to drawer 001 and reads the instruction there. It says, "Multiply the number on the pad by the number in drawer 021; leave only the answer on the pad." Since the number in 021 will represent the interest rate, the result of this multiplication would be the amount of interest earned. The clerk now goes to drawer 002, where he is instructed to "Add the number in 020 to the number on the pad." In so doing the new value of principal is computed. He then goes to 003, where the next instruction is, "Store the number on the pad in drawer 020, leaving the pad blank." (This storing of a number in a drawer always means that the number that was previously in that location is erased. However, the process of reading a number in a drawer does not affect that number.)

Now the clerk, upon going to drawer 004 for his next instruction, might find, "Go to storage location 000 for your next instruction." If so, he will again repeat the instructions in 000, 001, 002, 003, and 004 in turn, but this time using the new value of principal. This sequence of operations will be repeated over and over again. Each time this "loop" is repeated the number in 020 will increase, representing the value of principal with the accumulated interest for that number of interest periods. Thus if the initial number in 020 represented \$10,000 and the number in 021 represented 5 percent, then the values in 020 would represent \$10,500 after the first loop, \$11,025 after the second, \$11,536.25 after the third, and so on.

However, this process would not solve the problem as originally stated, which specified that the process must stop after 20 calculations.

Yet the set of operations resulting from the above instructions would go on indefinitely unless the procedure is modified. The modification would start with changing the instruction in 004 to "Put the number in drawer 022 on the pad." (The number in 022 will be 0 when the problem starts.) Next in 005 the instruction would be, "Add the number on the pad to the number in 023 and leave only the answer on the pad." Since the number in 023 is 1, the sum will be 1. In 006 the instruction is, "Store the number on the pad in location 022, leaving the pad blank." Thus a 1 is stored in 022 in place of the 0 which was there. The number in 022 thus indicates the number of interest calculations that have been made.

To use this to determine when to stop, the instruction in 007 is, "Take the number in 022 and write it on the pad." Then in 008, "Subtract from the number on the pad the number in drawer 024, leaving only the result on the pad." Since the number in 024 is 20, the first time this instruction is obeyed the result will be -19 . Now assume that in 009 there is a decision instruction of this nature: "If the number on the pad is 0 or positive, go to the next instruction in order; if the number is negative, erase it and go to drawer 000." Thus the clerk would in this case go back to 000 and repeat the entire process. However, the next time he came to 022 he would find a 1 in it which would be changed to a 2, leaving -18 after executing the instruction in 008 the second time. Thus in response to instruction in 009 the process would repeat again. The third time the result would be -17 , and so on. However, after the value of principal plus accumulated interest has been computed for the 20th time, the result of executing the instruction in 008 will be a 0 on the pad. Now when the instruction in 009 is encountered, the result will be that the clerk will go for the first time to 010 for his next instruction. Thus after 20 iterations the program of activity indicated by the instructions in the drawers results in a "branch" to an alternate course of action. The instruction in 010 can be simply "Stop" or it could be the first instruction of a sequence which will solve some other problem.

A digital computer generally solves problems in just this manner. The "storage" of a computer takes the place of the group of file cabinets. Each drawer is an individual storage location containing a "word" which is a sequence of numbers which may be data or an instruction. Each storage location is identified by an "address" much as houses are identified by different addresses. Instead of the pad of paper, a computer has an electronic storage device called an "accumulator." (This corresponds to the row of dials on the top of many manually operated calculators.) The equipment for storage and for performing the duties of the clerk are electronic and operate automatically at high rates of speed.

The speed of a digital computer means the speed at which it can perform arithmetic operations. This may be tens of thousands per second. The size of a computer generally indicates the amount of information that may be contained in its storage, possibly millions of words.

Note that the computer need do only a limited number of operations. In the program given above, the "operation" to be performed in storage locations 000, 002, 004, 005, and 007 are all the same. They differ only in the address of the number to be added to the number already in the accumulator. Thus each instruction consists of two parts, an operation portion and an address, or in other words, what to do and wherefrom to do it.

Numbers can be used to designate operations. Thus the *add* operation in drawers or storage locations 000, 002, 004, 005, and 007 can be arbitrarily designated to the computer as "1," the *subtract* operation in 008 as "2," the *multiply* in 001 as "3," the *store* of 003 and 006 as "5," and the *decision* operation in 009 as "7." If each word of a computer consists of 10 decimal digits with the operation digit in the 6th position and the address digits in the 8th, 9th, and 10th positions, then the above compound-interest problem can be specified to a computer as shown in table 1. This is a "program" for computer operation;

TABLE 1.—*Example of a digital computer program to compute compound interest*^a

Storage location	Instruction or number	Remarks
000-----	0000010020	Take principal.
001-----	0000030021	Multiply by interest rate.
002-----	0000010020	Add principal.
003-----	0000050020	Store new principal.
004-----	0000010022	Take tally.
005-----	0000010023	Add 1.
006-----	0000050022	Store as new tally.
007-----	0000010022	Take new tally.
008-----	0000020024	Subtract 20.
009-----	0000070000	Test for repeat.
.		
.		
.		
020-----	-----	Principal.
021-----	-----	Interest rate.
022-----	-----	Tally.
023-----	0000000001	
024-----	0000000020	

^a Tables 1, 6, 7, and 8 and figure 1 are reprinted by permission from "Digital Computer Primer," copyright 1959, McGraw-Hill Book Co., Inc.

sometimes also called a "routine." The first column indicates the storage location of the instructions and the data used in the problem. The column "Instruction or number" indicates the contents of each of these storage locations. The "Remarks" column is given merely to assist humans in understanding what is being done; the computer makes no use of it. A thorough grasp of the sequence of computer operations used in solving the compound-interest problem is essential to the understanding of digital computers.

Table 1 also shows how instructions can have the same form as numbers used as data and hence are interchangeable with data. Thus a computer can do arithmetic operations on its instructions, an interesting and useful characteristic of digital computers.

The above example also illustrates the different manner in which a computer and a human would solve a problem. The most important difference is the extreme detail of the instructions that must be given to the computer, and especially the manner in which these instructions must be stated in order to use the limited number of operations that a computer can perform. Contrast this with the instructions that one would give to a human to do the same job. Even if the calculation of compound interest had to be explained, it would not be necessary to go into such detail to insure that just 20 sets of calculations were made. It will also be noted that many of the operations are concerned with the manipulation of data (going to and from storage, etc.) rather than with the calculations themselves. These "bookkeeping" or "redtape" operations occupy a considerable portion of the program and of the time used in solving the problem. This applies also, however, to the use of a calculator for solving a problem. In a computer it is more obvious, as the instructions for these operations have the same general form as the instructions for doing the arithmetic itself.

THE PARTICULAR ARITHMETIC OF COMPUTERS

Aside from manipulation of data and decisionmaking, the essential operations of a computer are simple arithmetic. Since we all know how to add, subtract, multiply, and divide, it may be of interest to know how computers perform these functions. Generally their method differs from that of humans not only in the number system, but also in details of all arithmetic operations.

Binary numbers.—Most modern digital computers use a binary number system rather than the familiar decimal system. There are only 2 marks, 0 and 1, instead of 10 different marks, 0 through 9. Each position on either side of the binary point (corresponding to the decimal point) is a power of 2. This is illustrated by table 2, which shows the binary equivalent of decimal digits 0 through 9. The right-

TABLE 2.—Table of binary equivalents to decimal numbers

Decimal	Binary	Decimal	Binary
0.....	0000	5.....	0101
1.....	0001	6.....	0110
2.....	0010	7.....	0111
3.....	0011	8.....	1000
4.....	0100	9.....	1001

most binary position indicates the presence (by a 1) or the absence (by a 0) of a 1, the next position the presence or absence of a 2, the next a 4, an 8, and so on. Thus 0111 is $4+2+1$, or 7; 1001 is $8+1$, or 9; 1100010001 would be $512+256+16+1$, or 785; 110.011 would be $4+2+\frac{1}{4}+\frac{1}{8}$, or $6\frac{3}{8}$.

The reason for using a binary notation system is a practical one. Computers consist of devices which must be very fast and extremely reliable. The electronic devices which best meet these requirements are *two-state* (*bistable*) elements. Thus it is possible only to know whether these devices represent one *bit* of information, that is, either a 0 or 1. For example, whether a certain spot on a magnetic tape is magnetized in one direction or in the other direction, whether a vacuum tube is conducting current or not, a hole is punched in a card or it is not, etc.

Binary addition.—Another advantage of the binary number system is that binary arithmetic is quite simple. The binary addition table is given in table 3. The two numbers A and B can each have values of 0 or 1 so that there are only four possibilities to consider. An example of binary addition which uses all four combinations is given in table 4. However, binary representation means that about $3\frac{1}{3}$ times as many marks are needed to represent a number as with the

TABLE 3.—The binary addition table

A	B	Carry	Sum
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	0

TABLE 4.—Binary addition and decimal equivalent

Binary	Decimal
1 1 0 0	$8+4 = 12$
1 0 1 0	$8+2 = 10$
1 0 1 1 0	$16+4+2 = 22$

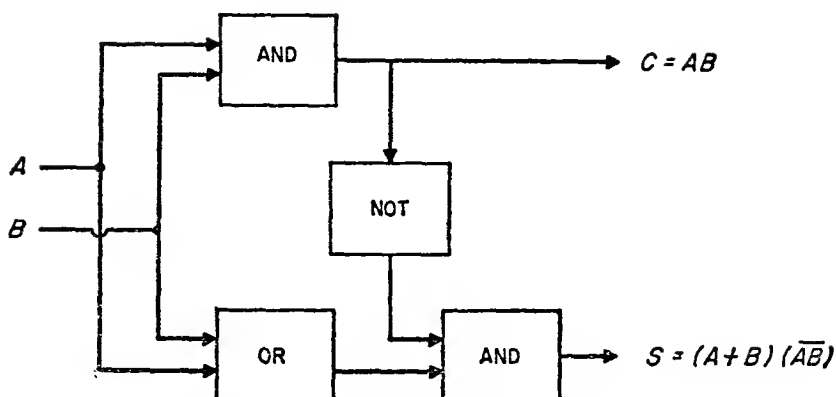


FIGURE 1.—Logical circuit for binary addition.

decimal system. For example, the 3-decimal digit number 785 requires 10 binary bits 1100010001 for its representation. Thus a binary computer would need to do $3\frac{1}{2}$ times as many binary operations to be equivalent to decimal arithmetic. However, this is a small price to pay for the advantages gained.

Referring back to table 3, we note that the conditions under which the *sum* digit is a 1 can be stated in words as, "when A is a 1 *or* B is a 1 *and* both A *and* B are *not* 1." Similarly, the condition for a 1 in the *carry* digit is, "when A is 1 *and* B is 1." The italicized words are important because they show how a binary addition operation can be expressed in words, *and*, *or*, and *not*, which are terms with logical meaning. The basic ideas of *and*, *or*, and *not* are familiar to everyone and their use in digital computer adders is the same as in the usually understood concepts of these terms. It is thus possible to draw a *logical* diagram for binary addition as shown in figure 1. This figure should be compared with the above word statement on binary addition and with table 3. They are equivalent ways of expressing the same thing.

The exact form of the adder in a digital computer varies from one computer design to another. The *and*, *or*, and *not* devices may use vacuum tubes, transistors, or magnetic devices. However, the logic, no matter how implemented, is the same.

Obviously, the addition operation must be done for each pair of digits in the two numbers to be added. Furthermore, in general, it is not simply a matter of adding just two digits together; it is necessary also to add the carry digit from the previous less significant addition. Thus a *full-adder* considers all three inputs. The device of figure 1 is a *half-adder* since it considers only two inputs. A full adder can be formed by using two half adders.

The "logical design" in digital computers extends to much more than the adder. Most of the other operations of the computer, including storage and decision operations, can be expressed in logical terms and hence be composed of the same electronic logical devices. The logical design of a computer is indeed very complicated, and most computers use many thousand logical elements.

So far we have considered only binary arithmetic. However, humans who put data into computers and read its answers are much more familiar with decimal numbers than with binary. Thus it is necessary to convert decimal numbers into some form of binary for input to a computer and to convert binary to decimal for output. The computer itself can do this converting. One way of doing this is to use combinations of binary digits to represent decimal digits in *binary-coded decimal* systems. Table 2 can be considered as an example of such a system. By such methods it is possible to use digital computers as if they were true decimal devices, although in fact they all are binary in some form or another.

Subtraction.—Subtraction can be, and sometimes is, done in a manner comparable to addition, that is, the subtraction table is formed, the logical equivalent determined, and the corresponding electronic circuitry built. However, many computers use the adder to do subtraction by representing negative numbers by a *complement* notation.

To understand this, consider table 5 where the left column gives the normal sequence of numbers from +5 backward to -5. It includes the concepts of zero and negative numbers. A complement system for representing these numbers is given in the right column. (For convenience, we consider only four digit numbers.) When the number is negative, the complement representation is the same as if the number were subtracted from 9999. The process of subtracting by adding the complement obviously is dependent on the fact that the complement can be obtained by a process simpler than subtraction, and indeed it can be done electronically.

The sequence of numbers in the right "counter" column is unusual but is as valid as the usual sequence if a set of rules is used for manipulation that differs somewhat from the usual set. Examples are given in table 6. Note first that results are always obtained by adding. Further, when the sum of the two numbers exceeds the four-digit size assumed, then the carry is added back to the right end of the sum. This last rule is a result of the way the sequence of numbers was defined. It is due to the fact that 0000 is not given in this sequence and that zero is represented by 9999. Again the reasons for this will not be considered here, but it does simplify the computer design. It is suggested that the reader try other examples using complements, such as adding zero (9999) to other numbers including itself.

TABLE 5.—Complement representation for negative numbers

Number	Counter	Number	Counter
5-----	0005	-1-----	9998
4-----	0004	-2-----	9997
3-----	0003	-3-----	9996
2-----	0002	-4-----	9995
1-----	0001	-5-----	9994
0-----	9999		

TABLE 6.—Counter column illustrates how complements can be used for handling negative numbers

Number	Counter	
(A) +5	0005	
-2	9997	
-----	-----	
+3	1 0002	Before end-around carry
	0003	After end-around carry
(B) +1	0001	
-4	9995	
-----	-----	
-3	9996	
(C) -2	9997	
-3	9996	
-----	-----	
-5	1 9993	Before
	9994	After

Multiplication.—Most computers do not multiply as such, that is, they do not use multiplication tables. They multiply by a process of repeated addition much as calculators do. The product of 3,514 by 7,596 could be obtained by adding 7,596 for a total of 3,514 times, but this would be a tedious process. However, by combining left shift operations (which are the equivalent of multiplying by 10 in a decimal machine or by 2 in a binary machine) with add operations, the number of additions required for multiplication can be considerably reduced.

The details of how such a multiplication could be done are given in table 7. Assume that the multiplier 3,514 is initially in columns 2 through 5 and that the multiplicand 7,596 is added in columns 6 through 9. Each time the multiplicand is added, the number in column 1 is reduced 1. When the number in column 1 is 0 the whole accumulator is shifted one position to the left and the process repeated. The 18 steps involved in this particular multiplication should be noted in detail. In this example only 3+5+1+4 or a total of 13 additions would be required.

Division.—Computer division also is generally done in a manner analogous to methods used in calculators. It involves successive

subtracting, testing, correcting, and shifting operations. Table 8 shows how 26,693,578 can be divided by 7,596 to obtain 3,514 as the quotient with a remainder of 1,234. After an initial left shift, the process involves subtracting the divisor 7,596 from columns 2 through 5 of the dividend until the remainder is negative. This indicates that one too many subtractions has occurred, so the program adds the divisor back and then shifts the remainder one position to the left. Then the process repeats. Since a 1 is added in column 9 for each subtraction which leaves a positive remainder, the final result is that the quotient (3,514) is in columns 6 through 9 and the remainder (1,234) is in columns 2 through 5.

TABLE 7.—*Steps in process of multiplying 3,514 by 7,596 to get 26,692,344 as a computer might do this multiplication*

Steps		Columns								
		1	2	3	4	5	6	7	8	9
1	Start	0	3	5	1	4	0	0	0	0
2	Shift	3	5	1	4	0	0	0	0	0
3	Add	2	5	1	4	0	7	5	9	6
4	Add	1	5	1	4	1	5	1	9	2
5	Add	0	5	1	4	2	2	7	8	8
6	Shift	5	1	4	2	2	7	8	8	0
7	Add	4	1	4	2	3	5	4	7	6
8	Add	3	1	4	2	4	3	0	7	2
9	Add	2	1	4	2	5	0	6	6	8
10	Add	1	1	4	2	5	8	2	6	4
11	Add	0	1	4	2	6	5	8	6	0
12	Shift	1	4	2	6	5	8	6	0	0
13	Add	0	4	2	6	6	6	1	9	6
14	Shift	4	2	6	6	6	1	9	6	0
15	Add	3	2	6	6	6	9	5	5	6
16	Add	2	2	6	6	7	7	1	5	2
17	Add	1	2	6	6	8	4	7	4	8
18	Add	0	2	6	6	9	2	3	4	4

LOGICAL USES OF COMPUTERS

So far we have considered digital computers only as they are fast equivalents of a clerk with a calculator. The clerk functions were assumed to be quite simple and the routine was spelled out in specific detail. It was over 100 years ago that Lady Lovelace⁴ said that a digital computer "has no pretensions to originate anything. It can do whatever we know how to order it to perform." The statement is still true. It can be interpreted to indicate the limitations of computers in that humans must think through in advance everything that a computer might do and tell the computer specifically the course of

⁴ Her early interest in computers is considered on p. 282.

TABLE 8.—How a computer might divide 26,693,578 by 7,596 to obtain a quotient of 3,514 and a remainder of 1,234

Steps		Columns									
		1	2	3	4	5	6	7	8	9	
1	Start	0	2	6	6	9	3	5	7	8	
2	Shift	2	6	6	9	3	5	7	8	0	
3	Subtract	1	9	0	9	7	5	7	8	1	
4	Subtract	1	1	5	0	1	5	7	8	2	
5	Subtract	0	3	9	0	5	5	7	8	3	
6	Subtract	-0	3	6	9	0	4	2	1	7	
7	Add	0	3	9	0	5	5	7	8	3	
8	Shift	3	9	0	5	5	7	8	3	0	
9	Subtract	3	1	4	5	9	7	8	3	1	
10	Subtract	2	3	8	6	3	7	8	3	2	
11	Subtract	1	6	2	6	7	7	8	3	3	
12	Subtract	0	8	6	7	1	7	8	3	4	
13	Subtract	0	1	0	7	5	7	8	3	5	
14	Subtract	-0	6	5	2	0	2	1	6	5	
15	Add	0	1	0	7	5	7	8	3	5	
16	Shift	1	0	7	5	7	8	3	5	0	
17	Subtract	0	3	1	6	1	8	3	5	1	
18	Subtract	-0	4	4	3	5	1	6	4	9	
19	Add	0	3	1	6	1	8	3	5	1	
20	Shift	3	1	6	1	8	3	5	1	0	
21	Subtract	2	4	0	2	2	3	5	1	1	
22	Subtract	1	6	4	2	6	3	5	1	2	
23	Subtract	0	8	8	3	0	3	5	1	3	
24	Subtract	0	1	2	3	4	3	5	1	4	
25	Subtract	-0	6	3	6	2	6	4	8	5	
26	Add	0	1	2	3	4	3	5	1	4	

action in each case. However, it is perhaps more correct to interpret the statement to mean that the limitations encountered in using computers are more of a reflection on our ability as humans to use them than on the computers themselves.

This is particularly true in the increasing use being made of computers as "logical" devices. While many useful human activities involve the use of arithmetic, many others require the solution of essentially logical problems. An executive managing a business concern, the officer directing a military operation, and a chess player are examples of people who must consider the often complicated situations in which they find themselves and "decide" on an appropriate course of action. There are probably many more practical problems requiring a logical solution than those calling for arithmetic operations. Thus the ability of computers to handle logic is particularly important. This ability may be considered an outgrowth of operations already mentioned. The decision operation, "If the number in the accumulator is zero or positive, go to the next storage location for

the next instruction; if it is negative, clear the accumulator and go to the storage location specified for the next instruction," is an example used in the compound interest problem. Most digital computers can use any of several decision operations.

The binary notation incidentally is convenient for logical operations. The 1 and 0 can represent words—*true* and *false*, *yes* and *no*—as well as they can represent numbers. Furthermore, we noted that electronic computers use logical elements such as *and*, *or*, and *not* to do arithmetic, and since logical problems are also generally stated in these terms, obviously the same devices used for arithmetic operations can be used for strictly logical operations.

As an example of a logical problem, let us consider the "logic" of a two-way switch. Assume two switches, A (the upstairs switch) and B (the downstairs switch) where 0 in each case represents the switch in the down position and 1 represents the switch in the up position. Assume further that the hall light is represented by S where 0 is the light being off and 1 is the light being on. Further, we know that "the hall light is on when the upstairs switch is up *and* the downstairs switch is down *or* the upstairs switch is down *and* the downstairs switch is up, but *not* when both switches are up *or* when both switches are down." How can this be represented in terms which have already been considered?

The answer is the A, B, and Sum columns of table 3. There the A and B represented binary numbers being added, but the logic is the same. When the condition of the hall light being on is restated as "the upstairs switch is up *or* the downstairs switch is up *and* both the upstairs switch *and* the downstairs switch are *not* up" then it is directly analogous to the word statement previously given for the sum digit in binary addition.

Of course, practical logical problems are much more complicated than indicated by this example, the number of different possibilities being enormous. To illustrate, let us consider how computers have been used for a process well recognized as a model of logic, that is, the proving of Euclidean plane geometry theorems.

Plane geometry theorem proving.—The use of a digital computer for proving theorems of plane geometry is illustrated by the example in figure 2, in which is given the machine proof that a certain construction involving the midpoints of two sides and two diagonals of a quadrilateral results in a parallelogram.

The general procedure used here for theorem proving is to work backward. Given as its goal to prove that a quadrilateral EFGH is a parallelogram, the computer first selects subgoals which would allow EFGH to meet the definition of a parallelogram. Each subgoal causes further subgoals to be generated, and so on. There may

PREMISES

 QUAD-LATERAL ABCD
 POINT E MIDPOINT SEGMENT AB
 POINT F MIDPOINT SEGMENT AC
 POINT G MIDPOINT SEGMENT CD
 POINT H MIDPOINT SEGMENT BD

TO PROVE

 PARALLELOGRAM EFGH

SYNTACTIC SYMMETRIES

 BA, AB, DC, CD, EE, HF, GG, FH,
 CA, DB, AC, BD, GE, FF, EG, HH,
 DA, CB, BC, AD, GE, HF, EG, FH,

PROOF

 SEGMENT DG EQUALS SEGMENT GC
 DEFINITION OF MIDPOINT
 SEGMENT CF EQUALS SEGMENT FA
 DEFINITION OF MIDPOINT
 TRIANGLE DCA
 ASSUMPTION BASED ON DIAGRAM
 PRECEDES DGC
 DEFINITION OF MIDPOINT
 PRECEDES CFA
 DEFINITION OF MIDPOINT
 SEGMENT GF PARALLEL SEGMENT AD
 SEGMENT JOINING MIDPOINTS OF SIDES OF TRIANGLE IS PARALLEL TO BASE
 SEGMENT HE PARALLEL SEGMENT AD
 SYNTACTIC CONJUGATE
 SEGMENT GF PARALLEL SEGMENT EH
 SEGMENTS PARALLEL TO THE SAME SEGMENT ARE PARALLEL
 SEGMENT HG PARALLEL SEGMENT FE
 SYNTACTIC CONJUGATE
 QUAD-LATERAL HGFE
 ASSUMPTION BASED ON DIAGRAM
 PARALLELOGRAM EFGH
 QUADRILATERAL WITH OPPOSITE SIDES PARALLEL IS A PARALLELOGRAM

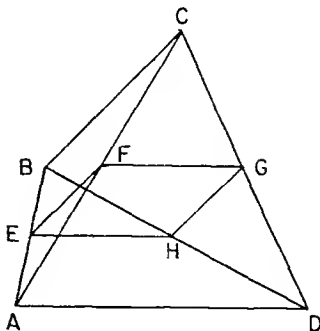


FIGURE 2.—Example of use of computer for logical process of proving a plane geometry theorem.

be several levels of such goals. The computer examines all these possibilities until a certain sequence of subgoals has been found that proves the theorem. It is necessary to keep the number of subgoals at each level as small as possible; otherwise the total number to be investigated could easily be too large to be handled even by large, fast digital computers. For example, if there were 10 subgoals generated for each goal or subgoal for a total of 6 levels, there would be over a million possibilities to consider. The limiting of the number of pertinent subgoals is done by checking each subgoal to see if it is consistent with the diagram. If it is consistent, it is kept as a possible step in the proof; otherwise it is rejected.

In the example of figure 2 the theorem was proved by demonstrating that it was reducible to the definition, "a quadrilateral with opposite sides parallel is a parallelogram." Intermediate steps in the proof used the theorems that "segments parallel to the same segment are parallel" and "segment joining midpoints of the sides of a triangle

is parallel to (its) base." Otherwise, the proof involves the definition of a midpoint and on assumptions based on the diagram.

It will be noted that the information must be specified to the computer in a degree of detail that may not be required in a human proof of theorems. In this example, the term "precedes DGC" means that points D, G, and C are collinear in that order. This may appear to be obvious, but it is needed for the proof. Similarly, much of what is given as "syntactic symmetries" appears to be "obviously" implied by the diagram. The usual proof of this theorem assumes these symmetries but does not necessarily consider them as formally as the machine must.

This example is a relatively simple one; much more complicated theorems have been proved. Furthermore, the brief description given here does justice neither to the magnitude nor the significance of the work being done in using computers to "prove" as well as compute. Obviously, the ability to prove geometrical or other theorems is not significant in itself; the important investigation is to show how these significant intellectual endeavors can be performed in terms of the simple operations which a computer can perform. Knowing this, it may be possible to extend these techniques to more useful intellectual activities.

FUTURE OF COMPUTERS

It is apparent that computers are acquiring much faster operating speeds and that their storage capacity is increasing while at the same time their physical size is decreasing. The cost per operation is going down, and it is certain that computers are going to be much more widely used than they are now. Many more thousands of people in the next few years will find that digital computers will play an essential part in their activities.

While computers will be increasingly used for arithmetic problems, it is also to be expected that they will find more and more uses of a logical nature. The proving of geometry theorems is only a step in the direction of using computers for nonarithmetic operations. It does illustrate the use of computers in situations in which the programmer cannot possibly anticipate all the possible courses of action. The computer is given very general instructions for determining its sequence of operations and will be able to adapt or "learn" as necessary to solve the problem presented to it. This should open new vistas for application of computers, and it has even been suggested that this use of computers has significant sociological implications.

Digital computers by their nature will also produce other indirect benefits. Lacking a tool that would permit doing a large number of operations to solve a problem, man has characteristically developed techniques using relatively few but necessarily complex operations.

This is especially true in the fields outside the exact sciences. However, scientists are now engaged in analyzing many operations in simple, fundamental terms suitable for use by computers. This has the desirable side result of increasing knowledge over and above that which can be fed to computers.

The limited number of operations that computers can perform compels all who use them to employ a common means of expression. The computer does not know whether the sequence of instructions which it performs were written by an accountant, linguist, philosopher, librarian, theologian, social scientist, physical scientist, engineer, or mathematician. Furthermore, its operations are independent of the natural language (English, French, or any other) of the person writing the program for the computer. At least at this level the activities in all sciences and of all nationalities are in a sense unified. This is especially interesting in an age when many fields of human endeavor are becoming more and more specialized and the problems of communicating between disciplines more difficult.

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Navigation—From Canoes to Spaceships¹

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[With 4 plates]

INTRODUCTION

IN 1786 John Hyacinth de Magellan of London presented 200 guineas to the American Philosophical Society as a gift, through which special gold medals were to be awarded from time to time. Under the terms of the gift, each of these medals should go "to the author of the best discovery or most useful invention relating to navigation, astronomy, or natural philosophy (mere natural history only excepted)." This specification of conditions makes it very probable that the donor intended to honor his lineal ancestor Ferdinando Magellan, who was killed during a Philippine Islands battle in April of 1521, after having navigated across all the unknown longitudes of the world's oceans. This earlier Magellan, the illustrious first circumnavigator of the globe, was a man whose vision, boldness, leadership, steadiness in adversity, and actual achievements give him an unassailable position as a very great member of the human race. It is a high honor for the author of this paper to be identified in any way with the name of Magellan, and he is deeply grateful to the American Philosophical Society for the 1959 Magellanic Medal. The citation mentions contributions to inertial guidance, a field in which the author has been active for many years as director of the Instrumentation Laboratory at the Massachusetts Institute of Technology. In this position, he has been fortunate to have the collaboration of a dedicated and able group of scientists and engineers who must rightfully receive a great share of any credit that may be due for pioneering applications of inertial devices to the problems of navigation.

Inertial navigation is properly the subject of primary interest for

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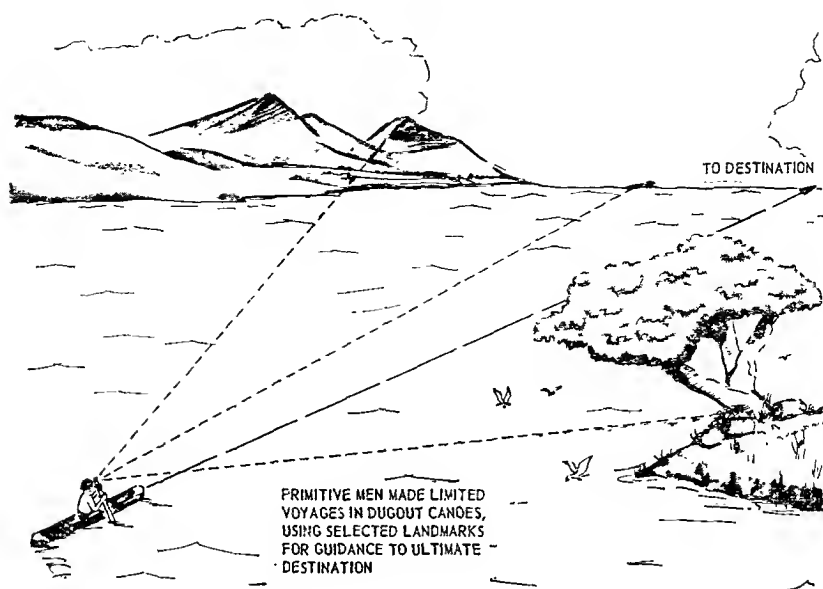


FIGURE 1.—Visual line-of-sight navigation.

this paper, but a brief discussion of guidance in general is needed to bring out an overall picture, with the inertial method given its place as one segment of a generalized pattern. To be complete, this pattern must include the navigational means that have been used or are available for terrestrial, marine, aeronautical, and space vehicles ranging from the dugout canoes of our caveman ancestors to the interplanetary ships that will be built in the near future for explorations of the solar system. Historical coverage and details of particular devices are beyond the scope of this paper, which is concerned only with the basic principles and methods that are used to solve the problems of navigation. Accordingly, references are omitted from the text, but a short bibliography related to gyroscopic devices and inertial navigation is provided for the convenience of those readers who may be interested in pursuing the subject further.

PRIMITIVE NAVIGATION

When one of our remote ancestors wished to go on a trip, he selected landmarks within sight and took his guidance from first one and then another, until he reached his destination (fig. 1).² If night or bad weather prevented him from seeing any landmark, he was forced to stop until conditions improved. Navigation with restrictions of this kind limited voyages to waters near extended shorelines and islands,

² The figures are drawn so as to be self-explanatory; hence, little detailed discussion of the figures appears in the text.

except for a few special cases where boats might be moved by known wind and water currents. This complete dependence on currents or on visible terrestrial objects was relieved many centuries ago by the discovery that under proper conditions heavenly bodies could be used to assist travel over the surface of the earth. In effect, the stars were found to act as points in a knowable space located at a great distance from the earth (pl. 1). The sun, the moon, and the planets did not appear to be fixed in this space, but followed paths that reduced their usefulness for the purposes of guidance. On clear nights, the star Polaris showed the direction of north and provided information on latitude by its angle above the horizon. Other stars with known positions in the pattern of the celestial sphere were also used, but celestial navigation remained an incomplete art for many centuries. The principal reason for this imperfection was the earth's rotation, which made it impossible to determine the angular position of the earth with respect to the stars. Without good information on this position, estimates of longitude necessarily remained of low quality.

CELESTIAL NAVIGATION

The key problem in longitude measurements was that of finding the rotational angle of the earth with respect to a reference position having known relationships to points fixed on the celestial sphere. Astronomical knowledge recorded in star tables and almanacs easily gave angles between lines of sight to celestial objects and the vertical at any terrestrial point, if the earth could be assumed to remain in a particular position. In practice, the earth never fulfilled this assumption, but continuously moved with respect to any possible reference position. Because the angular velocity of the earth among the stars was and is effectively constant and well known, an accurate means for indicating sidereal time (time based on rotation of the earth referred to the celestial sphere) would have made it possible to find longitude by fixing the angle of the earth from a selected reference position.

The basic problem of timekeeping for navigation was first solved during the 18th century by John Harrison, who received a prize from the British Admiralty for his achievement. The 19th-century developments of instruments and other devices that accompanied and followed Harrison's work on the marine chronometer—improved sextants, logarithmic multiplication, almanacs, and other aids—brought the art of celestial navigation by visual observations very close to the high level that it has today.

Celestial navigation is basically the art of using the celestial sphere as a reference space in which visible stars provide geometrical points for relating positions in terrestrial space to a system of coordinates outside the earth. These star lines of sight are the directions from

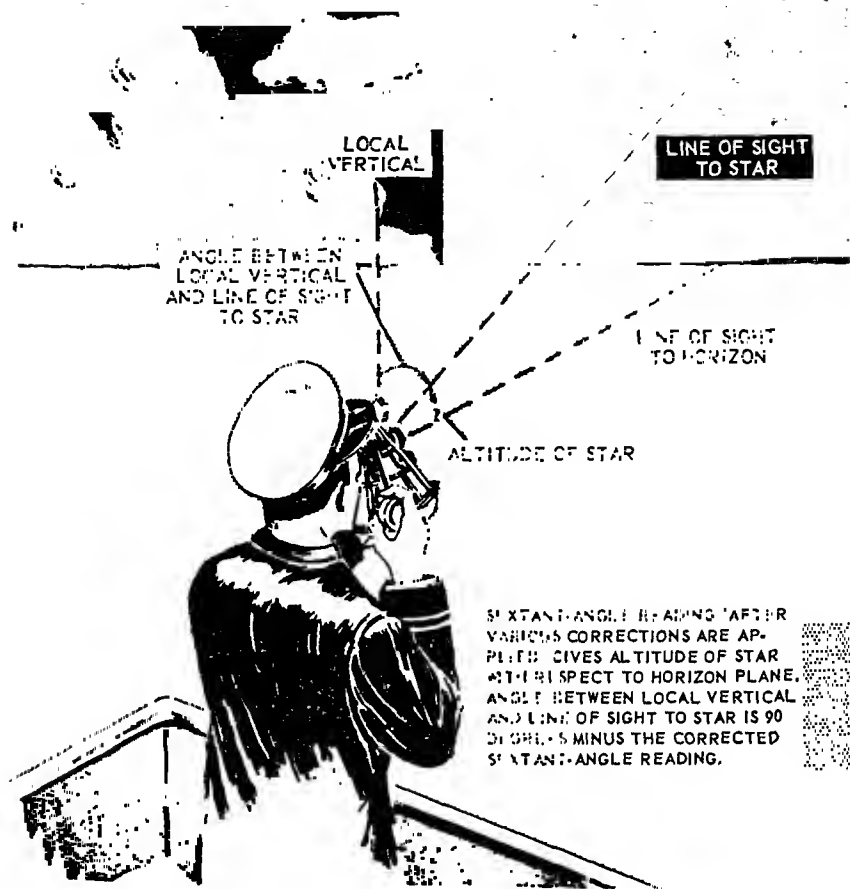


FIGURE 2.—Use of the sextant in celestial navigation.

which angles to the local vertical are observed at the terrestrial point to be located, by means of instruments like the sextant (fig. 2). Angle measurements of this kind are useful in navigation only if the positions that the observed stars occupy on the celestial sphere are known and if the instantaneous orientation of a selected meridian fixed to the earth is measured with respect to the celestial sphere.

Data on celestial-sphere points are available from the body of knowledge developed in descriptive astronomy and are recorded for the purposes of navigation in star tables and almanacs. The meridian selected as the reference for navigation is arbitrarily taken as the one passing through Greenwich. At any instant, the hour angle of this meridian may be determined with the aid of a chronometer reading, which provides knowledge of the time elapsed since the Greenwich meridian last occupied a reference orientation with respect to the

celestial sphere. The hour angle, star observations, and almanac data are the elements used to find locations on the earth by conventional methods of navigation.

The geometrical principles associated with the use of a nonterrestrial reference space for the purposes of navigation have been known and applied for centuries. Many techniques for using these principles, differing in details from the process that has been described, are possible. This fact is not important for the purposes of this paper, which is primarily concerned with describing the place of inertial methods among other ways of locating points on the earth's surface. It will appear that inertial navigation is geometrically analogous to celestial navigation. The essential difference lies in the use by inertial systems of gyroscopically controlled, rigid body members to serve the functions of the celestial sphere as a nonterrestrial reference space.

NAVIGATION BY RADIO AND RADAR

Navigation by the use of terrestrial landmarks, a very old art, was revolutionized during the first decades of the 20th century by the new science of electronics. This revolution came from applications of radio techniques to maintain radiation links between vehicles and points with known locations on the earth by the use of electromagnetic radiation having wavelengths much longer than those of visible light (fig. 3). Darkness, bad weather, distance, and obstructions that affect visual observations do not interfere with these long-wavelength contacts with landmarks that are radio stations or reflectors.

Radio direction finders are now common equipment for aircraft and marine vessels and serve as basic aids to navigation by giving bearings to known stations. Signals set up in the fashion of the "A" and "N" quadrants that are associated with the radio beams of civil airways have been used for several decades to guide airplanes. Higher accuracy and wider coverage in fixes are possible by applying the

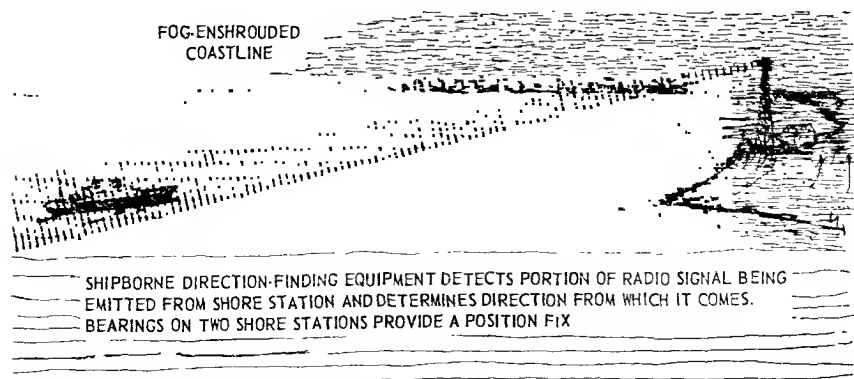
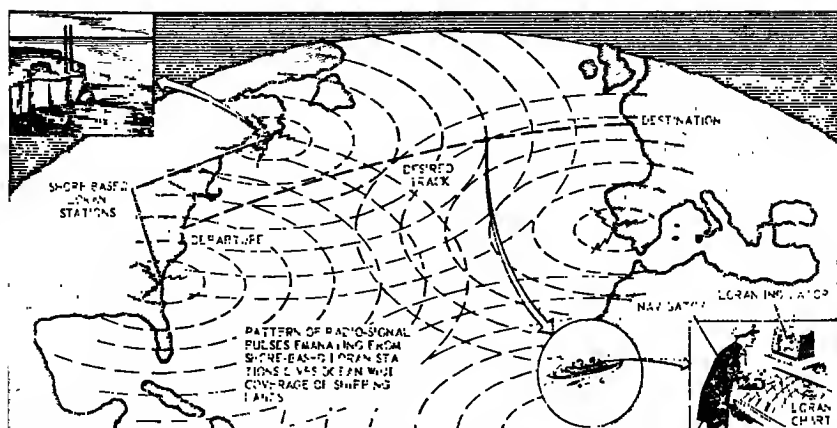


FIGURE 3.—Application of radio techniques to terrestrial navigation.



DEPARTURE AND DESTINATION ARE KNOWN IN EARTH COORDINATES (LATITUDE AND LONGITUDE). DESIRED TRACK IS ESTABLISHED FROM KNOWLEDGE OF DEPARTURE AND DESTINATION IN EARTH COORDINATES.

ACTUAL POSITION OF SHIP CAN BE DETERMINED BY MEANS OF LORAN. LORAN IS A HYPERBOLIC NAVIGATION SYSTEM IN WHICH THE NAVIGATING CRAFT RECEIVES SYNCHRONIZED PULSE SIGNALS FROM AT LEAST THREE KNOWN POINTS. TIME DIFFERENCE BETWEEN ARRIVAL OF SIGNALS FROM ANY PAIR OF THESE POINTS DETERMINES A LINE OF POSITION ON A LORAN CHART. BY MEANS OF THE CROSSING OF TWO SUCH LINES OF POSITION, THE CROSSING OF TWO

LORAN CHART SHOWS LORAN LINES OF POSITION SUPERIMPOSED ON GEOGRAPHIC PLOT. THEREFORE, LOCATION OF PRESENT POSITION IN LORAN COORDINATES GIVES DIRECTLY THE LOCATION IN EARTH COORDINATES.

FIGURE 4.—Navigation by means of loran.

principles of loran, and similar radio-navigation systems, in which the navigating vehicle receives synchronized pulse signals from at least three transmitting stations (fig. 4). The time difference between the signals received from any two stations determines a hyperbola-shaped line of position on the navigation chart. Use of at least one other transmitting station determines a second such line of position. The crossing of these two lines of position on the navigation chart establishes a highly accurate fix. With this navigation technique, the difficulties that beset visual observations of landmarks are substantially eliminated. Navigation by such radio-navigation nets, which cover wide areas of the earth's surface, is very useful for locating stationary points and slow-moving vehicles, but is not well adapted to situations that involve rapid maneuvers of fast vehicles.

Radar, which uses wavelengths shorter than those of the radio-navigation systems just described but longer than those of light, gives direct indication of distance from a single landmark. It is an excellent means for navigation by direct-line-of-sight contacts, with the restrictions associated with light substantially eliminated (fig. 5). The landmarks for radar may be ordinary terrain features and artificial objects, such as lighthouses, buoys, or other vehicles. Radar devices usually operate by comparing transmitted and reflected pulses. The time between sending and receiving for a particular pulse gives the distance to the reflecting surface in terms of the velocity of light.



FIGURE 5.—Navigation by use of radar.

An alternative method of using wavelengths of the radar spectrum for the purposes of navigation is to transmit continuous waves instead of pulses. This technique is particularly useful when the transmitter and reflecting surfaces are moving so rapidly with respect to each other that a measurable shift in frequency between reflected and transmitted waves exists. This frequency shift is a manifestation of the well-understood Doppler effect and is the basis for a number of radiation-contact guidance equipments that are classed as Doppler systems.

It is fair to state that toward the middle of the 20th century, radio and radar methods had substantially eliminated the difficulties that attend the use of visual contacts for the purposes of navigation by terrestrial landmarks. A number of other benefits had also appeared when visible light was replaced by longer wavelengths for navigational purposes: direct range and velocity measurements were available, working distances were greatly extended, direct-line-of-sight restrictions were removed, and complete automation of equipment became feasible. By about 1950, developments of equipment and methods had substantially exhausted the possibilities of improving navigation by terrestrial and celestial references. Improvements in details will always occur, but it is unlikely that these fields will see revolutionary changes in the future.

MODERN PROBLEMS IN NAVIGATION

All the advances in methods, theory, tables, instruments, and techniques that appeared during the course of several thousand years to perfect the art of navigation combined to solve the same problem that confronted the first caveman navigator. This problem was and still is that of finding position of the earth from information provided by

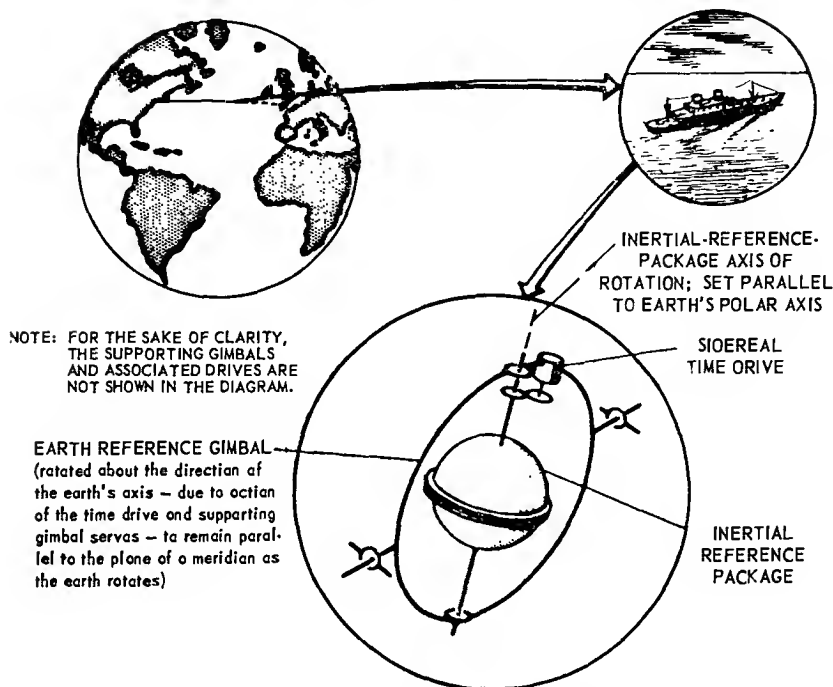
time and by radiation contacts with objects having known locations in terrestrial space or celestial space. Navigation progressed with the perfection of chronometers and other instruments, and with improvements in the means for sensing radiation-contact information, until at the present time a state of development exists for these elements that approximates their ultimate possibilities. It now remains for new methods to overcome the problems in navigation that began to emerge during the last half of the fifth decade of our century. These problems, which are not solvable by radiation-contact methods, originated largely from needs associated with modern military operations and flights by vehicles moving in the emptiness of space outside the earth's atmosphere, although civilian applications will surely become important in the future. The new difficulties in navigation appear because the vehicles involved must operate in situations where it is undesirable or impossible to maintain radiation contacts of any kind with outside points.

Bombers flying to attack targets deep within well-defended enemy territory will surely not have an environment of cooperative ground stations and can expect the enemy to take all possible measures for interfering with the operation of such radiation-contact equipments as radios and radars. Submarines designed for the underwater launching of ballistic missiles must have an accurate and continuous knowledge of position during long periods of submerged cruising near enemy shores. Ballistic missiles, which to be effective must be designed for simultaneous launching in salvos of considerable numbers, need to have self-contained guidance systems in order to keep ground installations within feasible limits of size and cost. Satellites, lunar craft, and interplanetary vehicles need navigational equipment designed to make the most effective use of the available weight and volume capacity, so that there are strong reasons for working out designs based on the best possible combinations of radiation-contact components and inertial elements.

These examples serve to illustrate the nature of the new requirements on navigation equipment that have developed during the past 10 years. These requirements reduce to the necessity for navigation systems capable of giving high-quality performance during periods that include a considerable number of hours without radiation contacts. In terms of the basic geometry involved, this means that navigation equipment must include a completely self-contained means for providing geometrical references (fig. 6).

Inertial principles applied through the medium of gyroscopic action (see bibliography) make it possible to realize geometrical reference members, in the form of rigid bodies, that are capable of serving the functions of celestial space in navigation. To be satisfactory, these reference members must hold initially established orientations with

WHEN DEPARTURE AND DESTINATION ARE BEYOND LINE-OF-SIGHT
CONTACT AND DIRECT RADIATION CONNECTION IS NOT POSSIBLE,
INERTIAL REFERENCE COORDINATES MAY BE USED FOR GUIDANCE



INERTIAL-REFERENCE-PACKAGE ORIENTATION IS INITIALLY ACCURATELY ESTABLISHED WITH RESPECT TO INERTIAL SPACE, THAT IS, WITH RESPECT TO CELESTIAL SPACE (FOR THE PURPOSES OF PRACTICAL GUIDANCE, INERTIAL SPACE AND CELESTIAL SPACE ARE EFFECTIVELY IDENTICAL). THIS MAY INVOLVE THE USE OF DEVICES NOT INCLUDED IN THE INERTIAL GUIDANCE EQUIPMENT.

HIGH-PERFORMANCE INERTIAL-REFERENCE GYRO UNITS (GYRO UNITS WITH LOW DRIFT RATES) SUPPLYING CORRECTION SIGNALS FOR SERVO-DRIVEN GIMBALS OPERATE TO ACCURATELY HOLD THE INERTIAL-REFERENCE-PACKAGE ORIENTATION WITH RESPECT TO INERTIAL SPACE DURING THE PERIOD GUIDANCE IS REQUIRED.

A SPECIFIC FORCE RECEIVER SYSTEM WITH SCHULER TUNING MAY BE USED TO ACCURATELY INDICATE THE VERTICAL IN MOVING VEHICLES.

MEASUREMENT OF THE ANGLES BETWEEN THE VERTICAL AND A MEMBER FIXED WITH THE PROPER ORIENTATION TO THE EARTH REFERENCE GIMBAL GIVES PRESENT POSITION OF THE VEHICLE ON THE EARTH.

FIGURE 6.—Guidance by substitution of inertial reference coordinates for celestial coordinates.

high accuracy under conditions of operation. The essential features of systems based on reference members of this kind are discussed in the sections that follow.

SELF-CONTAINED GEOMETRICAL REFERENCES FOR NAVIGATION BY APPLICATION OF GYROSCOPIC PRINCIPLES

Gyroscopic effects are mainly associated with the mechanical behavior of a balanced, symmetrical rotor spinning rapidly about its

axis of circular symmetry and mounted in gimbals, or carried by some other means, that allow it to have rotational freedom about directions at right angles to its spin axis. The action of such a gyroscope (a name applied by Foucault to devices with the features just described) depends on Newton's law of motion, which states that a particle of mass acted on by a force has a rate of change of its velocity vector in the direction of the applied force. The magnitude of this rate of change is directly proportional to the magnitude of the force and is inversely proportional to the moving mass. Any space in which Newton's law of motion applies is by definition an inertial space. The possibility of inertial navigation depends on the fact that matter used for equipment parts responds to applied forces by motions with respect to an inertial space that is essentially identical with the space determined by the fixed stars.

In a moving, rigid body, such as a gyroscopic rotor, interactions among individual particles combine to give the rotor an angular momentum that is equal to the product of the moment of inertia about the spin axis and the angular velocity of spin. The consequence of Newton's law of motion as far as it pertains to a gyroscopic rotor is that a torque applied to the rotor about any axis at right angles to the spin axis causes the spin axis to rotate toward alinement with the torque axis. The angular velocity associated with this rotation, which is called precession, is proportional to the magnitude of the applied torque and is inversely proportional to the magnitude of the rotor angular momentum.

When the torque applied to a gyroscopic rotor is zero, the angular velocity of precession is zero, and the spin axis perfectly holds its existing orientation with respect to inertial space. For the purposes of navigation, the important fact is that the space in which a torque-free gyroscopic rotor holds its spin axis in a fixed direction is identical with the celestial space associated with the fixed stars. This means that a geometrical reference member controlled by two or three gyroscopic rotors designed for substantially torque-free operation will hold its orientation almost perfectly with respect to celestial space. Thus, a mechanical member inside a navigation system can supply all the necessary geometrical-reference information, without the need for external radiation contacts of any kind.

In addition to this feature, which supplies the essential need of self-contained navigation equipment, gyroscopic inertial members are more convenient for reference purposes than celestial space, which must be used through the medium of a few nonsystematically located fixed stars. This convenience stems from the fact that torque-free gyroscopic rotors do not tend to move toward any preferred direction, but hold any orientation they may have when applied torques are reduced

NOTE: FIXED STARS, ETHERWIDE CELESTIAL SPHERE



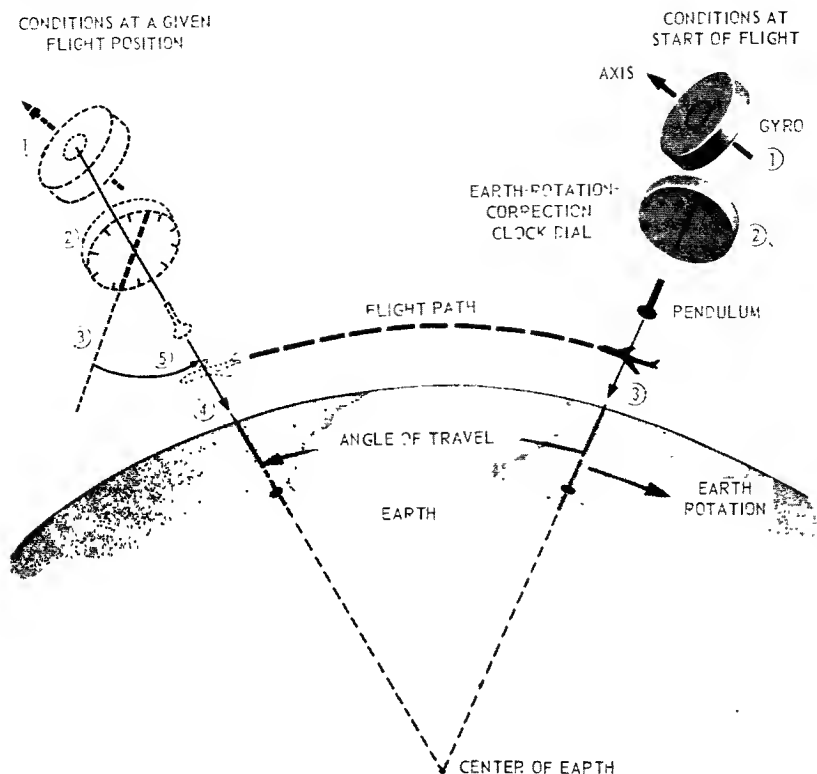
Geometrical relationships between terrestrial and celestial coordinates.

CELESTIAL SPACE, ESTABLISHED BY THE FIXED STARS, MAY BE USED TO PROVIDE REFERENCE COORDINATES FOR GUIDANCE.

AT ANY GIVEN INSTANT, AS ESTABLISHED BY A CHRONOMETER OR SOME OTHER ACCURATE TIME-INDICATING DEVICE, THE POSITION OF THE EARTH COORDINATE SYSTEM WITH RESPECT TO THE CELESTIAL SPACE COORDINATE SYSTEM IS KNOWN FROM ALMANAC INFORMATION.

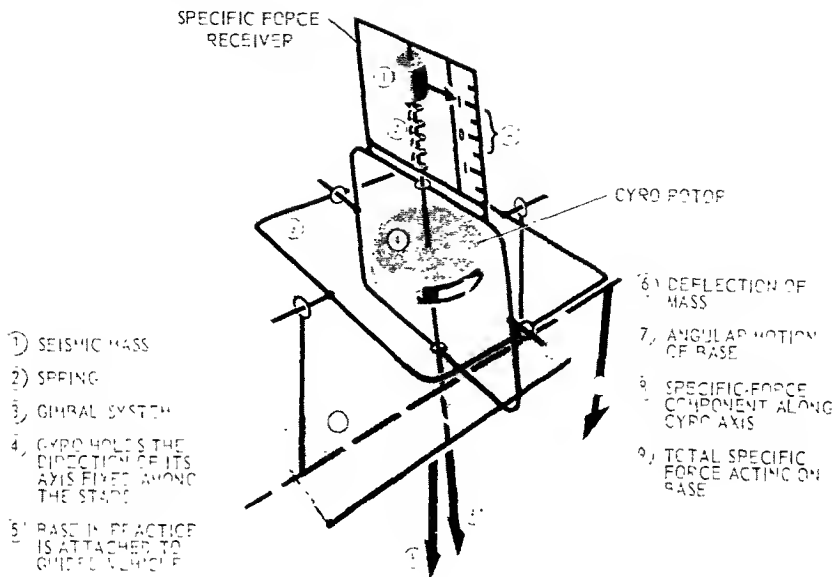
AT A PARTICULAR INSTANT, THE PRESENT POSITION MAY BE ESTABLISHED IN CELESTIAL SPACE BY LINES OF SIGHT TO PROPERLY CHOSEN STARS

THIS PRESENT POSITION IN CELESTIAL REFERENCE COORDINATES MAY BE TRANSFERRED TO EARTH COORDINATES BY THE USE OF ACCURATE TIME AND INFORMATION ON THE RELATIONSHIP BETWEEN CELESTIAL COORDINATES AND EARTH COORDINATES.



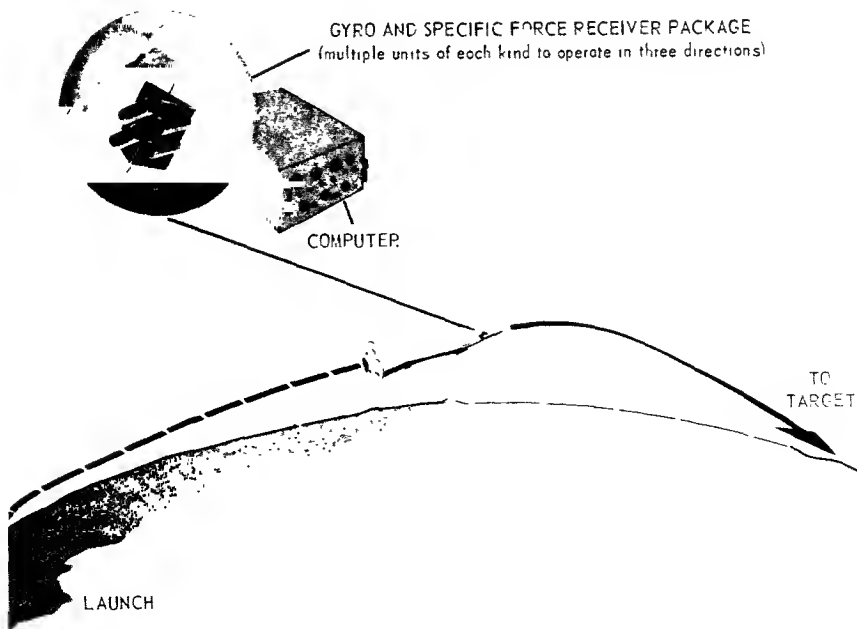
- ① GYRO HOLDS AXIS DIRECTION CONSTANT WITH RESPECT TO FIXED STARS, THAT IS, WITH RESPECT TO AN INERTIAL REFERENCE SPACE
- ② DIAL ROTATION WITH SIDEREAL TIME CORRECTS FOR EARTH ROTATION TO GIVE AN EARTH REFERENCE SPACE
- ③ DIRECTION OF GRAVITY AT START OF FLIGHT, WITH RESPECT TO THE EARTH REFERENCE SPACE
- ④ DIRECTION OF GRAVITY AT FLIGHT POSITION REPRESENTED BY DOTTED LINES, WITH RESPECT TO THE EARTH REFERENCE SPACE
- ⑤ INDICATED ANGLE OF TRAVEL IS PROVIDED BY ANGULAR DISPLACEMENT, IN EARTH REFERENCE SPACE, OF DIRECTION OF GRAVITY WITH RESPECT TO ITS POSITION AT THE START OF THE FLIGHT

Inertial system simplified to illustrate elements of navigation for vehicles moving at substantially constant altitude.

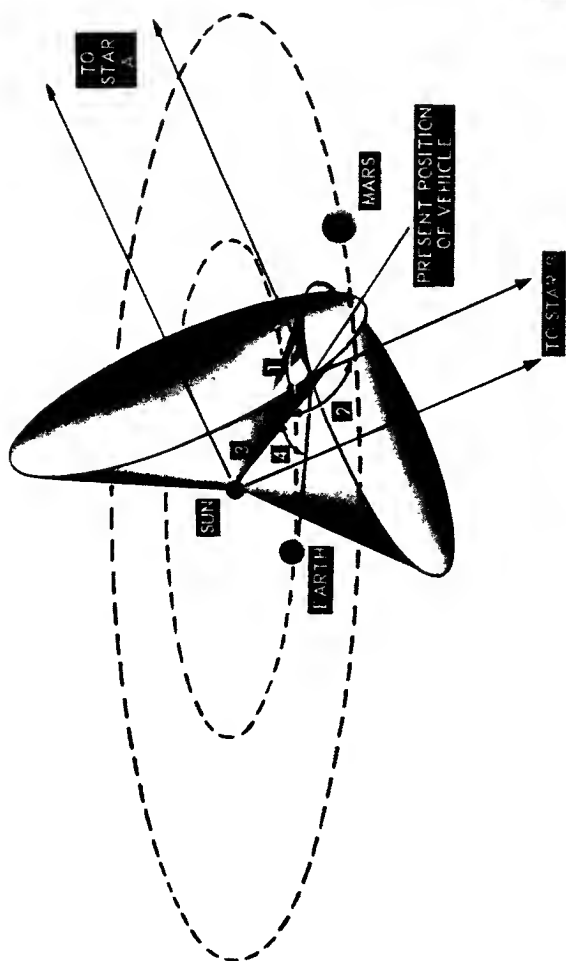


NOTE: TO SIMPLIFY DIAGRAM, ONLY SINGLE-DEGREE-OF-FREEDOM OPERATION IS SHOWN.

1. Two-degree-of-freedom gyro and single-degree-of-freedom specific force receiver illustrating elements of inertial guidance for vehicles in arbitrary motion with respect to the earth.



2. Inertial guidance for a ballistic missile



- ① ANGLE BETWEEN LINE OF SIGHT TO SUN AND LINE OF SIGHT TO STAR A ESTABLISHES PRESENT POSITION IN SPACE TO BE ON A CONICAL SURFACE CENTERED ABOUT THE LINE FROM THE SUN TO STAR A. ANGLE BETWEEN AXIS OF CONE AND SURFACE IS EQUAL TO 180° DEGREES MINUS THE ANGLE BETWEEN THE TWO LINES OF SIGHT
- ② ANGLE BETWEEN LINE OF SIGHT TO SUN AND LINE OF SIGHT TO STAR B ESTABLISHES PRESENT POSITION TO BE ON A SECOND CONICAL SURFACE THAT IS SIMILARLY DEFINED
- ③ INTERSECTION OF THE TWO CONES (WHICH COINCIDES WITH LINE OF SIGHT TO SUN) ESTABLISHES A LINE OF POSITION IN SPACE.
- ④ ANGLE BETWEEN LINE OF SIGHT TO SUN AND LINE OF SIGHT TO EARTH, OR SOME OTHER PLANETARY BODY, WHOSE POSITION IS KNOWN, DETERMINES PARTICULAR POSITION ALONG KNOWN LINE OF POSITION, TO ESTABLISH FIX IN SPACE

The geometry of a fix in space.

to zero. Therefore, the orientation chosen for any given situation may be the one that allows the simplest or most convenient configuration of the required mechanism. For example, causing one of the support axes of the gyroscopic package to operate in parallelism with the earth's axis of rotation makes it possible for a simple sidereal clock drive (such as represented in fig. 6) to compensate for the rotation of the earth. The orientation of the reference member remains fixed with respect to inertial space about this polar axis, so that the first support gimbal outside of the sidereal time drive remains parallel to some meridian on the earth. By mechanical adjustments, this artificial meridian may be alined with any selected earth meridian. The combination of this artificial meridian inside the navigation equipment and the artificially established direction of the earth's polar axis provides an adjustable earth reference space that is derived from an adjustable inertial reference space and a time drive. Positions on the earth are fixed by determining the direction of the local gravitational vector with respect to this mechanically established earth reference space (pl. 2).

The inertial-system configuration just described was chosen because of its simplicity for the purposes of explanation. Various other configurations are possible. For example, the gyro units of the inertial reference member may be designed to receive continuous torque inputs that cause the member to change its orientation with respect to inertial space so that it indicates the direction of the local vertical as the system moves over the earth's surface. In a system of this kind, changes in position with respect to the earth are indicated by integrations of torque-controlling signals to calibrated gyro units. Each signal corresponds to an angular velocity component of the reference member with respect to inertial space, and one integration gives the associated angular displacement. Correction of this displacement for rotation of the earth by a time signal and multiplication by the radius of the earth gives a component of distance traveled over the earth's surface. The same procedure applied to the other components of inertial-reference-member rotation gives the corresponding components of travel. Combining all the travel components gives the indicated resultant movement of an inertial navigation system over the earth. Relating this indicated movement to the point of departure gives the indicated position of the vehicle carrying the navigation equipment at any instant.

Another configuration of inertial navigation equipment places the inertial reference member in an arbitrary orientation and employs computers to produce information on indicated position. This arrangement is often used for the guidance of ballistic missiles.

PRACTICAL ASPECTS OF INERTIAL REFERENCES

In practice, inertial references involve many factors that cannot be mentioned in this paper because of space limitations. Some of these factors are associated with design details, while others are common to all systems. One of these common factors is the necessity for establishing the desired inertial-reference-member orientation prior to any period of use for the system containing the member. This orientation must be based on inputs generated by means outside the gyro units of the reference member and supplied to these units as angular-velocity command signals that become zero when the proper orientation is reached. For example, an optical system using a light-sensitive cell tracker pointed toward Polaris and a servomechanism arrangement can be used to drive an axis of the inertial reference member toward alinement with the earth's axis of rotation. Similarly, pendulum signals can be used for properly setting the reference member in a selected angular position about the polar axis.

Any actual gyro unit is imperfect in the sense that its rotor can never be completely torque-free, with the result that the spin axis does not hold its direction perfectly with respect to inertial space. However, by proper design and construction, it is possible to make the resultant of undesired torque components very small and to keep the uncertainty parts of these components at still lower levels. Drift rates having an order of magnitude of one one-thousandth of earth's rate (earth's rate is 15° per hour) can now be expected from commercially available gyro units. For high performance, the rotors of these units cannot be used directly to generate motion-resisting torques sufficient to control heavy supporting gimbals. However, techniques are available that make it feasible for the member carrying the spin-axis bearings of the rotor to operate under conditions of substantially complete freedom from interfering torque components. In units that take advantage of this possibility, deflections of the case of the unit with respect to the rotor do not provide heavy torque but are used only for the generation of control signals, a service that imposes virtually zero torque loads. By using these signals as command inputs to amplifiers controlling the servomotors that drive the supporting gimbals, the effects of friction and other disturbing torques may be overcome so completely that the structure carrying the gyro units remains accurately in an orientation determined by the gyro spin axes.

SPECIFIC-FORCE-RECEIVER SYSTEMS FOR INDICATIONS OF THE VERTICAL AND THE DISTANCE TRAVELED

Inertial navigation systems designed to operate on or near the earth's surface must have some provision for indicating the direction

of the local vertical. This direction gives indicated position through its orientation with respect to the artificially established earth coordinate reference of the system. On a platform fixed to the earth, the problem of indicating the vertical is easily solved by means of a simple pendulum. On a moving platform subjected to horizontal accelerations, a simple pendulum is no longer satisfactory, because of interfering effects introduced by these accelerations. This interference is unavoidable because, by Einstein's principle of equivalence, the mass of any body in its response to a gravitational field is identical with the mass associated with inertia-reaction effects. Thus a pendulum bob hanging along the vertical under gravity is deflected when its point of support is given any horizontal acceleration. Under the accelerations usually experienced by moving vehicles, a simple pendulum may well have erratic deflections of several degrees. Disturbances of this magnitude are completely unacceptable for the purposes of navigation where the required maximum accuracy magnitude is of the order of 1 mile. When it is remembered that on the earth's surface 1 minute of arc between local-vertical directions corresponds to a distance of 1 nautical mile, the uselessness of simple pendulum arrangements for navigation is apparent.

Errors in local-vertical indications under conditions of erratic acceleration of a moving vehicle may be reduced to satisfactory limits by designing the indicating system so that it has a proper dynamic behavior. The required characteristic is that of responding to a horizontal linear acceleration component by an angular acceleration about a horizontal axis at right angles to the linear acceleration. When the angular acceleration has a magnitude equal to the linear horizontal acceleration divided by the radius from the center of the earth to the moving platform, vertical indications change in step with variations in position. A system with performance of this kind is said to have Schuler tuning; this is in recognition of Professor Schuler, who first published the theory of such arrangements. When Schuler tuning is used, indications of the vertical remain accurate in the presence of arbitrary horizontal accelerations. On the surface of the earth, Schuler tuning corresponds to a period of about 84 minutes. Any practical system possessing the features suggested in plate 2 would have to use a pendulum with this characteristic.

Because of the small distance between the pivot and the center of gravity that would be required in a simple physical pendulum with Schuler tuning, a pendulum of this kind is not physically feasible. The practical solution for this problem is to use an equivalent pendulum system based on a servodriven gimbal-supported platform carrying sensing elements that respond to gravity and acceleration. Amplifiers in the feedback loops are designed so that electronic cir-

cuits act to introduce the required dynamic performance. By variation of circuit parameters, it is possible to adjust both the period and the damping so that optimum results are achieved under operating conditions.

The sensing components required for Schuler-tuned equivalent pendulum systems are arrangements in which gravitational and inertia-reaction forces acting on a seismic mass (a body designed to act as the receiving element of a sensor) cause deflection against some restraining means in a way that generates an output signal representing the resultant input force. This resultant is made up of the force acting to move the seismic element in the direction of the gravity field and the inertia-reaction effects that tend to cause the seismic element to lag behind the linear acceleration of the sensing unit. It is convenient to consider gravity and inertia-reaction effects as combining to form the specific force, which is the resultant force per unit mass acting on a body due to gravity and acceleration. A simple pendulum is a specific-force receiver in which the suspended mass tends to align itself with the direction of the specific-force input vector. Many other kinds of specific-force receivers are in use in which the output signal represents the specific-force component acting along an input axis that has a fixed direction with respect to the case of the sensing component. Devices of this kind appear as essential elements in all inertial navigation systems.

INERTIAL NAVIGATION SYSTEMS FOR VEHICLES MOVING AT SUBSTANTIALLY CONSTANT ALTITUDE

Navigation systems used in vehicles supported by ground, air, or water normally move in surfaces that are substantially spherical about the center of the earth, so that the specific-force input for specific-force receivers is practically identical with gravity. This means that it is feasible to indicate the direction of gravity by means of an equivalent pendulum system with Schuler tuning. Inertial equipments for use in ground vehicles, aircraft, surface ships, and submarines all take advantage of this fact by basing their indications of vehicle location on the orientation of an indicated vertical member with respect to an earth reference member positioned by a gyroscopic inertial reference system and sidereal time. In some cases, the inertial reference member holds its physical orientation among the stars, while in other cases the member moves, and its rate of change of orientation with respect to inertial space acts as the input for a computer whose output is navigational information.

Many designs are possible for inertial systems based on indications of the local vertical by an equivalent pendulum with Schuler tuning. Several different equipments have been constructed by various com-

mercial organizations and tested far enough to prove the feasibility of inertial navigation, but it is to be expected that several years of effort will have to pass before final decisions as to the best type of equipment can be made.

INERTIAL GUIDANCE SYSTEMS FOR BALLISTIC MISSILES AND SATELLITES

Ballistic missiles are subjected to high accelerations for short periods of high thrust during the phase of boosting through the atmosphere and then coast in free fall until they reenter the air before striking target areas. In this situation, it is not feasible to base guidance on indications of the local vertical. During the boost phase, the inputs for specific-force receivers are greatly different from gravity, both in direction and in magnitude. During the coasting phase, free fall reduces the net specific force to zero, so there are effectively no inputs for specific-force receivers. Reentry and the terminal phase are again subject to accelerations due to air resistance that cause the specific force available as the input for guidance equipment to be greatly different from gravity. These facts combine to prevent systems that operate by indicating the local direction of gravity from being useful in equipment for guiding ballistic missiles. Some other mode of operation must therefore be used to meet the operating requirements of such equipment.

Inertial guidance for ballistic missiles is achieved by eliminating terrestrial-space reference equipment and solving the guidance problem by means of specific-force receivers fixed in an artificially oriented space that is associated with a gyroscopic reference number (pl. 3, fig. 1). To mechanize this arrangement, a rigid body member supported by a servodriven gimbal system carries the necessary gyro units and, in addition, serves as the mounting for a set of three single-degree-of-freedom specific-force receivers with their input axes set at right angles to each other (pl. 3, fig. 2). With this configuration, the total specific force acting on the gyro-oriented reference member is sensed in three components in a special set of coordinates having known geometrical relationships to terrestrial space and to celestial space. Signals representing these components are generated by the specific-force sensors and transmitted to a computer. This computer, acting on these inputs and on information stored in its memory banks, works out the instantaneous location of the missile under guidance, compares this location with the desired location on the proper path, and generates command signals for correcting the direction of the missile. These command signals are received by the missile control system, which changes the orientation of the thrust vector with respect to the missile so that the necessary changes in the missile path are made.

Ballistic-missile guidance is carried out in artificially established inertial-space coordinates, with the target considered as a moving

point because of the earth's rotation. For the purposes of this guidance method, gravity is regarded as merely one component of the resultant specific force, without any particular attention to its direction as it is related to location on the earth. Time is also an input to the system, but it is one of several factors for the computer, rather than the means for determining the orientation of the earth.

Satellites may be put into orbit by inertial guidance, but inertial equipment is not essential but may be helpful during long periods of coasting flight. Very probably, inertial devices will be useful in sensing angular-velocity inputs for control purposes. It is also likely that gyroscopic stabilization will be utilized to assist radiation-contact devices carried by satellites in tracking the earth and other celestial bodies.

INTERPLANETARY GUIDANCE

Interplanetary vehicles must operate for long periods of time with only tenuous radiation contacts with either their points of departure or their destinations. During the midcourse phases of long interplanetary trips, it may be desirable for the guided vehicle and its equipment to be able to operate without outside assistance from manned installations. Conditions will be close to ideal for radiation contacts with celestial bodies, and techniques are well developed for acquiring and tracking sources of optical wavelengths. Data from the operation of optical trackers, combined with accurate time from devices based on the natural-frequency vibrations of atoms or elastic bodies and with almanac data stored in digital computer memories, provide all the information needed for the accurate navigation of space vehicles. In effect, celestial-space coordinates are used for this purpose, with locations of the guided vehicle determined from the angular relationships among lines of sight to the sun, the stars, the observable planets, and satellites such as the moon. These lines of sight can be automatically sought out by optical trackers and may be maintained either by continuous tracking or by the use of gyroscopically controlled reference members with their orientations set from radiation-contact information.

For example, the process of navigation might start by acquiring and maintaining the line of sight from the vehicle to the sun by means of a heliotracker (pl. 4). The second step would be searching for a selected star over a conical surface about the heliocentric line by means of a star tracker whose angle setting is based on an accurate indication of time and data stored in the memory of a computer. The angle measured between the lines of sight to the sun and this star establishes in celestial coordinates one of the cones of position shown in plate 4. This process is repeated with a second star. Then the angle between

the sun line of sight and a planet line of sight is used to determine the location of the vehicle along the line of intersection of the two cones.

CONCLUSION

Navigation has been discussed in general terms, with emphasis on the geometrical aspects of the problems involved. Radiation contacts with terrestrial and celestial points provide means for navigation under ordinary circumstances. In the special situations that arise when radiation contacts are not feasible, inertial methods are available. Practical applications of these methods are too new for details of equipments to be settled, but it is certain that navigation of the future will employ many different arrangements, ranging from all-radiation-contact systems to all-inertial systems with various compromise arrangements in between. We can look forward with confidence to rapid and interesting developments in the old art of navigation.

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Photography of the Ocean Floor¹

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[With 9 plates]

It was inevitable that, once the photographic method of recording pictures had become established, its use as a means of reproducing underwater scenes and the life of the sea should have been considered. The first serious efforts to take underwater photographs were made by Boutan in 1893, working in the clear waters of the Mediterranean off the coast of France. Although his only successful photographs were made by a diver-operated camera, he nevertheless foresaw the value of an automatic camera which could be lowered to the sea floor in places inaccessible to a diver. His failure in this field was due to the lack of suitable illumination and to the primitive nature of the apparatus then available.

Surprisingly enough, automatic underwater photography was not followed up until nearly 50 years later, although diver-operated cameras taking both still and ciné film had been extensively developed. In 1940, M. Ewing, A. Vine, and J. L. Worzel [1]² successfully took photographs of the sea floor with a fully automatic camera. Under the stimulus of wartime needs, photography of the sea floor, especially of wrecks, and of sea-floor conditions for the purpose of sound propagation studies, became an established technique. After the war, it was quickly realized that this was a technique that could be used to investigate the great ocean depths and to observe the abyssal fauna and geology in situ. Following the American lead, many laboratories throughout the world have developed their own deep-sea cameras and have used them for a great variety of purposes.

CAMERA DESIGN

Fortunately for underwater photography, the wavelength for which the attenuation of light through water is a minimum lies in the middle

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² Numbers in brackets refer to list of references at end of article.

of the visual range. In the deep sea we find that water has great clarity owing to the absence of suspended matter and that for ranges up to 20 feet or so no loss of definition of the image occurs. Thus a conventional camera viewing through a plain glass window with suitable illumination will give a good picture. There is, however, one optical problem that arises if high-resolution, wide-angle photographs are required. The path of light from water into air is refracted at an oblique interface, the refraction being a function of the wavelength. Hence, the angular field of view of the lens is reduced and, unless monochromatic light is used, the image off the axis is not sharp. The first effect is not important unless maximum coverage is required. The second effect can be corrected by placing in front of the camera a suitable lens that will introduce an equal amount of chromatic aberration in the opposite sense.

In the shallow water around the coasts and on the continental slope, the turbidity of the water is an important limiting factor. In many places, especially in harbors and river mouths where photography has important practical applications, the visibility is reduced to a foot or less, and if photographs are required, a means has to be found of displacing the turbid water in the object field with clear water. This is a difficult practical problem, and photography in shallow water is, therefore, of only limited use.

The practical design of a deep-sea camera can best be illustrated with reference to the one designed and built at the National Institute of Oceanography (England) [2]. The camera consists of three basic units, the photographic unit, the flashlight unit, and the acoustic transmitter or "pinger" unit. Each of these has its own watertight casing and its own power supplies. The watertight cases are required to withstand external pressures up to 10,000 lb./in.² The simplest cases for the purpose are cylindrical, and, in order to keep the overall weight to a minimum, an internal diameter of 3 inches was chosen. The cases are of light alloy having a wall thickness of three-fourths of an inch and being sealed throughout by O-ring seals. The window for the camera is made of Perspex in the form of a truncated cone 1¼ inches thick, in a conical seating.

The photographic unit comprises a lens and shutter, 15 feet of 35-mm. film enabling a series of up to 100 pictures to be taken, and a motor and gearbox, driven by torch batteries, to move the film automatically after each exposure. This unit is shown in plate 1, figure 1. The electronic flash unit is of conventional design working from dry batteries and generates 100-joule flashes. The pinger unit, which is triggered when a photograph is taken, transmits signals through the water to the operator on the surface telling him that the camera has reached the bottom. It is housed in one of the tubes forming the

framework. Some such form of indicator is an important part of any equipment which is required to be lowered to the bottom of the deep sea, since it is impossible, in the presence of the additional tension due to up to 3 miles of wire hanging in the water, and the variations in tension due to the rolling and pitching of the ship, to feel the change in tension on the wire when the camera reaches the bottom. The pinger normally emits signals at a slow rate while the camera is in midwater, but when it touches bottom, the rate is increased.

The camera is triggered by a weight, combined with a small sampler, that is suspended below the camera. When this touches bottom, the flash, synchronized with the shutter opening, is triggered, the pinger signals the surface, and the film is moved to the next frame. The operator can immediately raise the wire several fathoms so that the camera itself never touches bottom. After a minute or so another picture can be taken and the process repeated. A series of pictures can thus be taken while the ship drifts. In this way a photographic profile can be made of such deep-sea features as seamounts or the edges of abyssal plains. Any standard black-and-white or color film can be used, and, if desired, stereoscopic pictures can be taken by using two separate photographic units. The underwater camera is shown in use on R.R.S. *Discovery II* in plate 1, figure 2.

THE RESULTS OF PHOTOGRAPHIC EXPLORATION

During the past 3 years many hundreds of photographs of the sea floor, at depths varying from a few fathoms to nearly 3,000 fathoms, have been taken by workers at the National Institute of Oceanography. The photographs have an immediate interest in revealing for the first time a part of the earth's crust never before seen by man but their full scientific value cannot be realized unless they are related to the broader environment in which they are taken. Thus they should be taken in conjunction with a topographic survey of the area and with systematic sampling of the bottom by such means as coring and dredging, so that the details revealed in the photographs can be interpreted in terms of specimens that can be examined at close quarters. This, however, is a counsel of perfection, and there is seldom time for all the necessary data to be acquired.

In reviewing the results of the photographic program to date it is convenient, first, to consider the photographs in relation to the different regions and features of sea-floor topography and, second, to illustrate various topics of especial interest that have emerged from a study of the photographs. In some instances, color photographs are used to illustrate various points, since these give a truer representation of the bottom.

REGIONAL CLASSIFICATION

The nearest and most accessible region of the sea floor is that of the Continental Shelf, where the water depth seldom exceeds 100 fathoms. The coastal part of the shelf has been frequently photographed by divers and so will not be considered further here. It is difficult to generalize about the nature of the bottom on the shelf, since there is as much variety here as there is in the geology of the land. Apart from rocky outcrops and beds of seaweed in the shallower water, a lot of the shelf off the coast of Europe consists of sand, shells, gravel, and mud. The presence of abundant mollusks and other large shells and of coarse gravel is typical of shallow-water shelf deposits. Frequently, one finds the sand patterned by ripplemarks, the product of the strong tidal streams and currents around the continents.

As we proceed toward the deep ocean, we come to the continental slope which begins quite suddenly, the depth increasing to 2,000 fathoms or more in 20 miles. The slopes are often cut with deep canyons carrying the shallow-water sediments out to the deep sea. Apart from these canyons, the slope is a region of deposition of the fine silt and clay material that has been carried out from the coast. Photographs show a smooth, featureless bottom suggesting fairly rapid sedimentation.

In deep water, the bottom of the great ocean basins can be divided physiographically into several regions. Apart from seamounts, ocean trenches, and mountain ranges, the bottom is more or less completely covered with a blanket of sediment many hundreds of feet thick. Some areas reflect the buried topography in an undulating bottom, and others have an extraordinary flatness associated with sedimentation by turbidity currents. These are currents of water containing sediment in turbulent suspensions that can flow along gentle gradients on the sea floor for many hundreds of miles. At close quarters, however, both the abyssal plains and the undulating bottom are very similar. The ooze is soft enough for extensive reworking by bottom-living organisms which leave tracks, burrows, mounds, and other evidence of their existence. In some cases there are indications of the originator of these features, such as the impression of a five-armed star on the top of many of the small humps, but more often one is left to guess when and how they were made. Occasionally, one is lucky enough to see a sea cucumber or a brittlestar crawling along the bottom, or some tube worms or a sponge sticking out of the ooze, but the density of life in abyssal depths is very low. Typical photographs of this region are shown in plate 2, figures 1 and 2, and plate 7, figure 1.

The great mid-Atlantic ridge divides the Atlantic Ocean into eastern and western basins. This vast chain of mountains has an obscure

origin, and much work has been done to elucidate its structure but without any conclusive results. Photography has shown that its rocky peaks are areas of extremely low sedimentation and have been subject to recent and violent upheaval. Plate 3, figure 1, shows steep slopes and freshly cleaved rocks resembling the scree found on land. Other photographs have shown basins of sediment covered with patches of shinglelike material that may in fact be colonies of a deep-sea shellfish. On the whole the rocky peaks appear poor in sessile fauna, a fact consistent with the idea of a geologically recent disturbance.

By far the most interesting and varied collection of sea-bottom photographs has been taken on the volcanic seamounts that rise out of the deep basins. In general the greater the depth, the less dense is the faunal population. The attraction of a seamount to the abyssal fauna is doubtless partly related to its geological formation. There are a great many exposed rocks and boulders in varying states of fracture; there are sands and oozes in great variety. These offer to the fauna a variety of footholds and, to fishes, shelter in which to hide from their foes. Possibly nutrients are concentrated in the water in these regions by local upwelling due to obstruction of the waterflow and by the solution of minerals from the rocks themselves. Examples are shown of the continuous type of submarine lava flow, of the bedrock, of broken boulders and shingle, and of the current-swept sand with ripplemarks. Often it appears that the fauna of one seamount differs from that of another and that where in one place for instance one finds predominantly crinoids, in another there may be sponges. However, this differentiation may be only the result of inadequate sampling techniques, and until more pictures are taken it cannot be confirmed. Photographs taken on seamounts are illustrated in plate 3, figure 2, plates 4, 5, and 6, plate 7, figure 2, plate 8, and plate 9, figure 1.

Photographs were taken of one bank of especial interest off Cape Finisterre. Galicia Bank, which is divided from the Continental Shelf by a depth of 1,500 fathoms, has a structure that may be related more nearly to that of the continent than to that of the ocean floor. Rocks dredged from it are of two distinct types; limestones and a collection of dark metamorphic rocks. The photographs strongly suggest that the limestone is locally derived, whereas the metamorphic rocks are erratic and have possibly been carried by icebergs from the north. (Pl. 9, fig. 2.)

SPECIAL PROBLEMS

The geological interpretation of rocks seen in bottom photographs is extremely difficult unless hand specimens can be examined. How-

ever, some very interesting features of deep-sea geology have been revealed. In particular, photographs have indicated the distribution and the environment of the rocks. In the Pacific Ocean, millions of tons of potential manganese ore have been found scattered on the deep-sea bed in the form of manganese nodules. The exposed surface of nearly all rocks in deep water slowly acquires a coating of manganese dioxide and this can be used to indicate which way up a piece of rock lay. In plate 3, figure 1, the white patches on the broken boulders are probably places where a manganese coat is lacking and one can infer from this that they have been disturbed quite recently from the position in which they have lain for many thousands of years. The cauliflower texture seen on the rock on the left of plate 9, figure 1, is due to a similar manganese crust.

Underwater lava flows have been found photographically in a region where a dredge has been unable to pick up any loose material from the bottom. In plate 3, figure 2, photographed from the American research vessel *Vema*, the roundness of the rocks is similar to that of the pillow lavas found on continental rocks and believed to have been solidified under water. Once again the nodular manganese coating is plainly visible.

The ripplemarks found in the deep sea are of great interest to sedimentary geologists. At one time it was thought that the deep sea was a region of very small currents and that the existence of ripplemarks in a sedimentary rock indicated deposition in shallow water. We now have direct evidence of ripplemarks being formed in deep water together with scour and sand drifts around obstacles in the sand. Plate 6, figure 1, shows these features in globigerina sand at a depth of 1,700 fathoms.

Almost every photograph taken in the deep ocean shows evidence of some kind of life existing there. In most cases it is impossible to give a specific name to the animals found, since the systematic classification has been based on detail that is often not visible in a single picture. However, the pictures do show the animals in their normal habitat and in undamaged condition, whereas many of the dredged specimens have suffered damage in collecting, and distortion in the resultant pickling and storing in formalin. Plate 6, figure 2, shows an unusual holothurian that was previously known only from extensively damaged specimens collected by H.M.S. *Challenger* in 1875.

One of the most fascinating puzzles posed by the pictures is the identification of the tracks and burrows found over the wide areas of the soft bottom. One must appreciate that with the sediment accumulating at the slow rate of only a centimeter or less in a thousand years, a track once made will be visible for a very long time. Thus the density of tracks reflects the activity of several thousand years. Some

of the tracks are made by animals on the surface and some by animals beneath it. Plate 2, figure 2, shows the broadest tracks found (about 4 inches across) and is representative of many such tracks found beneath the Atlantic. A similar track, but with much more pronounced transverse marks was photographed by Zenkevitch from the Russian research ship *Vityaz*, in the Pacific. Although the central part of the track is raised, it must have been formed by an animal on the surface because of the regularity of marking. A possible interpretation is that the track was made by a mud-feeding animal which scoops the mud into its mouth with some form of arms or tentacles, producing transverse marks and a ridge of ooze, the central depression being made by a trailing tail. Possible animals to fit this theory are decapod crustaceans and holothurians of the type shown in plate 6, figure 2.

Other interesting tracks are the sinuous and the spiral forms. These appear to have been made by worms burrowing just below the surface and stop suddenly when the worm burrows downward. The shapes of these tracks provide interesting evidence of the way in which an animal can search an area most economically and systematically.

Many other interesting problems arise out of these photographs concerning the relationship between fauna and their environment. Photography will doubtless be used more and more in the future to study deep-sea marine ecology.

FUTURE USE OF UNDERWATER PHOTOGRAPHY

It is clear from the above discussion that deep-sea photography has its place in any investigation that includes the sea bottom. A photograph is second best to direct observation, but until bathyscaphes become more common, direct observation is not possible. It may be advantageous, in sampling the bottom, to attach a camera to the corer or dredge to estimate the sampling technique more efficiently. Certainly, if it becomes a practicable proposition to drill into the solid rock of the seabed, photographic control would be most desirable.

The deep-sea camera has been used as a tool in a number of ways other than those described. Fish, squid, and the deep scattering layer have been photographed in midwater using suitable triggering devices, and the camera has been incorporated as the recording method for the measurement of currents on the sea floor. Doubtless many other uses will be found in the future.

ACKNOWLEDGMENTS

I am grateful to the director of the Lamont Geological Observatory, New York, for permission to publish the photographs shown in plate

3, figure 2, and plate 4, figure 2. Plate 1, figure 2, is published by permission of the British Petroleum Co.

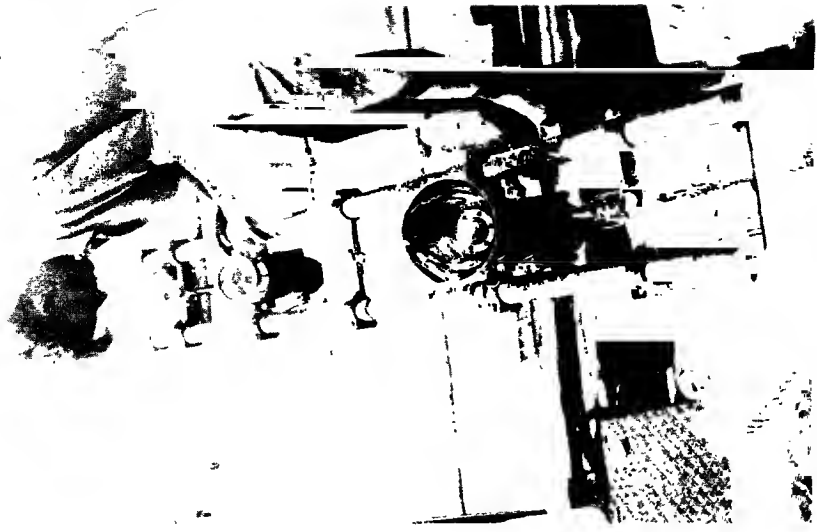
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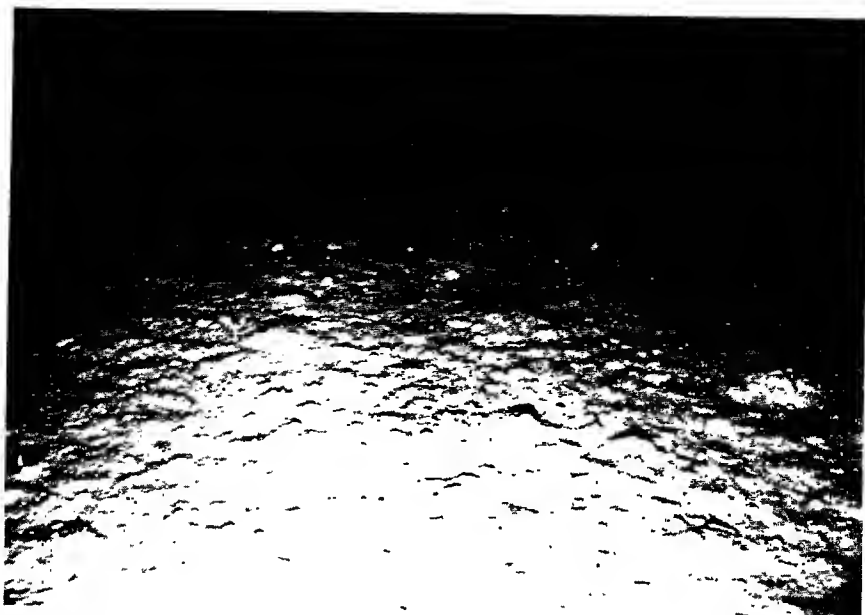
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1. Photographic unit, showing batteries, motor, gear box, film drive mechanism, and lens. (This model has no shutter.)



2. Deep-sea camera in operation. Units are acoustic transmitter (at the top), photographic unit, flash unit, bottoming switch, trigger weight, and sampler.



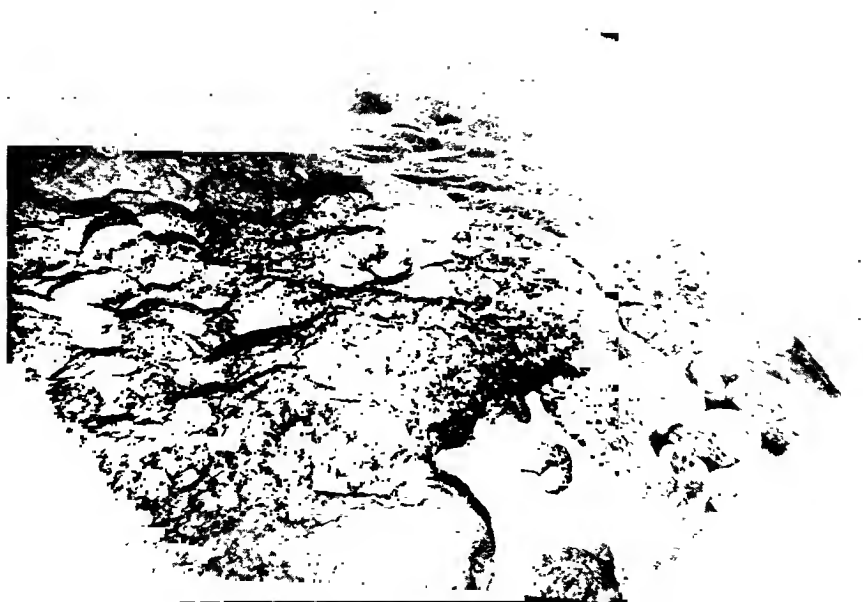
1. Typical view of deep-ocean basin sediments in 2,550 fathoms, showing the extensive activity of bottom fauna in creating burrows and mounds.



2. A 4-inch-wide track in the ooze of a deep basin (2,890 fathoms) perhaps made by an animal traveling on the surface and scooping the mud into the central ridge while feeding



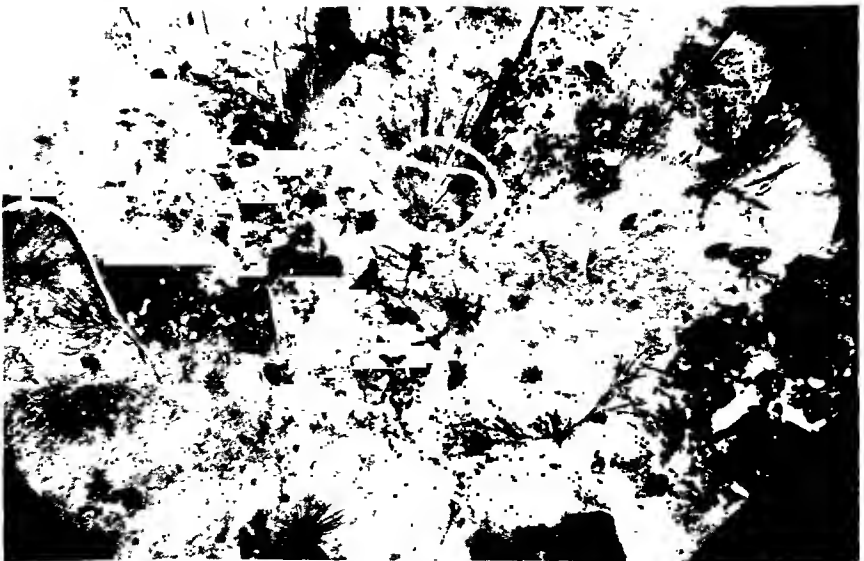
1. Scree slopes on a peak on the mid-Atlantic ridge at a depth of 800 fathoms, showing absence of sediment and some signs of recent disturbance 3425.3, 46° 34' N, 27° 14' W.



2. Oblique view of an underwater lava flow on the side of a volcanic seamount at 720 fathoms. V4.12.8, 35° 12' N, 15° 18' W.



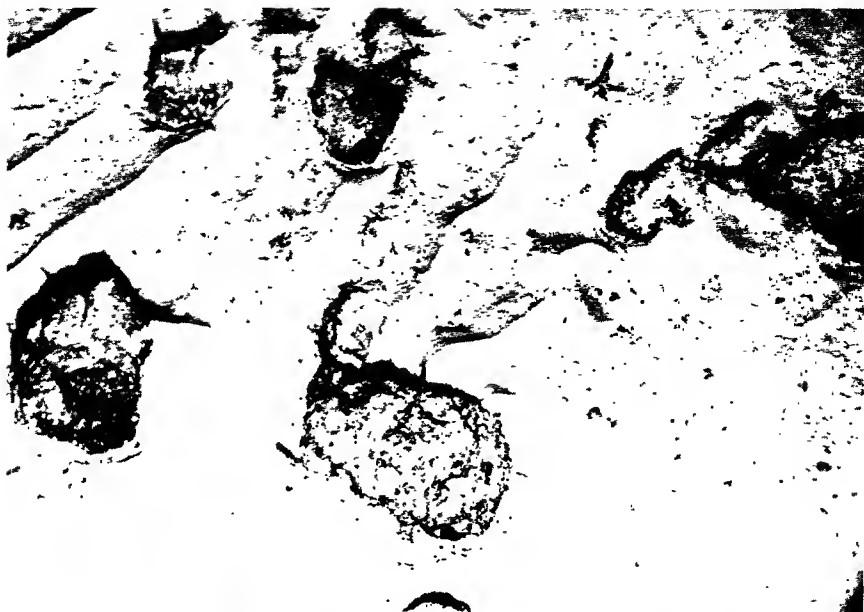
1. Rock and calcareous sand on a seamount at 1,580 fathoms. Feathery comatulid crinoids are seen attached to branching corals. 3755 S, 41°12' N, 15°14' W.



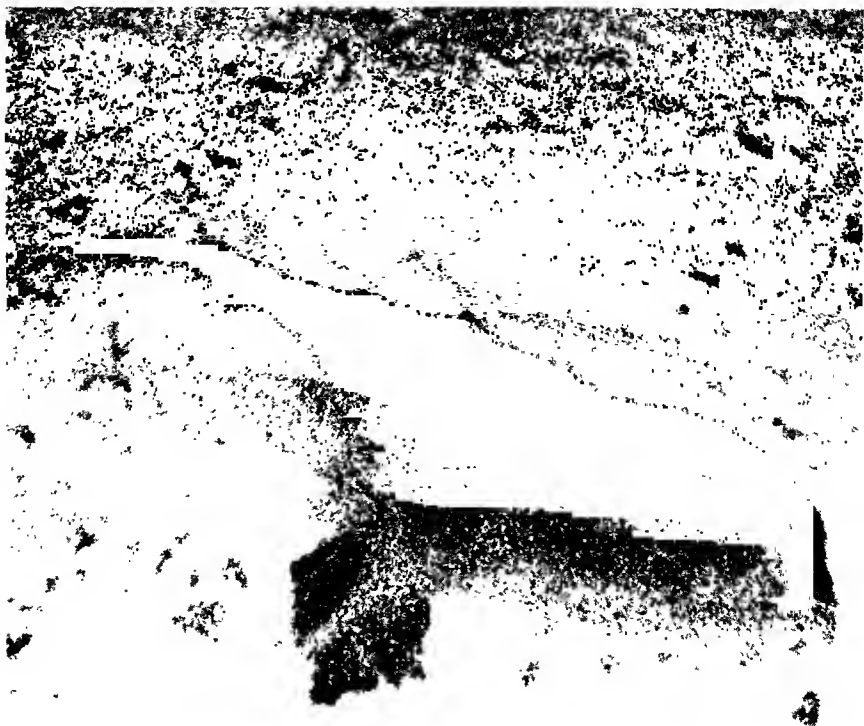
2. Gorgonians, pennatulids, sponges, corals, and sea-urchins on the top of a seamount at 75 fathoms, showing the increased faunal population in shallow water. 3418 10, 35°10' N., 12°55' W.



Outcrop of bedrock on a volcanic seamount at 800 fathoms, showing a zed fish, three varieties of gorgonian anemones, and some singular debris deposited by current action. The central gorgonian is more than 5 ft high. 34°55'26.34" N., 116°32'W.



1. Ripple marks, scour, and sand drifts in a calcareous sand on a seamount at 1,710 fathoms. 37°55' 29", 41°12' N., 15°14' W.



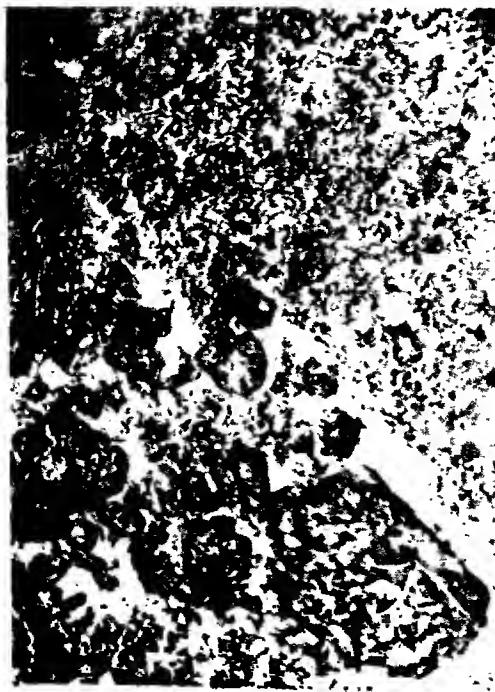
2. A rare holothurian (*Penia* sp.), 8 inches long, showing feet, branching tentacles around its mouth for feeding, and its "sail" in a collapsed condition (extreme left). Depth 1,560 fathoms. 37°55.4', 41°12' N., 15°14' W.



2. Loose boulders of volcanic rock lying on the side of a scarp at 1,780 fathoms. Two 5 mm. and 2 mm. climoids are attached to the rocks and miscellaneous 0.2 mm. clasts are scattered between. 5757.4



1. Sub-photocamera zone on an abyssal plain 2,900 fathoms. A pale blue sea-life sits on a burrow (12 inches in diameter). Note the radial feeding tracks of a banded animal. 5770.15.



1. Boulders and cobbles lying in loose sediment on the side of a seamount at 1,840 fathoms. Of special interest is the gravel-size material lying in the lower right half of the picture which, on close examination, has the appearance of mollusk beds. 3757 10.



2. Five- and ten-armed crinoids attached to boulders on the side of a seamount at 1,840 fathoms. A pink brittlestar and a red deep-sea prawn (in the shadow of a rock, lower right) can be seen. 3757 12.



1. Bryozoans and a bryozoan attached to broken coral at 1,890 fathoms. The surface of the left hand rock has the typical "manganese" appearance associated with the growth of a manganese crust. 3757-19



2. On Gilbert Bank at 350 fathoms. The pale rocks (probably fine-stones) are locally derived, whereas the dark rocks have been carried from elsewhere. 3766-6

History of a Tsunami

By ELLIOTT B. ROBERTS

Captain, Coast and Geodetic Survey (Retired)

[With 1 plate]

ON July 9, 1958, the rock layers 9 miles deep under the Fairweather Range of southeast Alaska grew tired of the unrelenting strains associated with a geological uplift going on in the region. At 15 minutes and 52 seconds after 10 in the evening, Pacific standard time, while it was still light in that high latitude, they broke apart in a shearing motion that started a chain of very weird events.

For a few moments the scattered people in nearby parts of Alaska were unaware of that subterranean cleavage. All seemed peaceful and quiet—even the normally restless waters of the Pacific were as nearly calm as they ever are. At Yakutat, 115 miles to the northwest, postmaster John Williams and CAA employee Robert Tibbles, with their wives and a widowed cannery owner, Jeanice Welsh Walton, were preparing to leave Khantaak Island, where they had been picking strawberries on Point Turner near the harbor navigation light. The Williams couple were some distance off the point in a launch, while the others were embarking in another boat. Quiet, late-evening sounds drifted from Yakutat and the few cabins around Dry Bay to the southward. Still farther south, mountain-girt Lituya Bay lay near the foot of 15,320-foot Mount Fairweather itself. Inside La Chaussee Spit at the bay entrance were two boats, the *Badger*, aboard which Bill and Vivian Swanson, of Auburn, Wash., lay asleep, and the *Sunmore*, occupied by Orville Wagner, of Idaho Inlet, and his young wife Mickey. Farther in, near Lituya's south shore, were Howard Ulrich and his 7-year-old son Junior, in the 38-foot *Edrie*. Just in from a day of fishing, they all sought a night's shelter before undertaking another day of labor in the Alaskan Gulf. Geologist Virgil Mann, of the University of North Carolina, and a party of 16 men were camped on the shore of Lake Crillon, among the hills 8 miles southeast of Lituya, preparing to move next morning to an abandoned cabin on Cenotaph Island almost in the exact middle of the bay. Ten Canadian mountaineers just down from history's second ascent of

Fairweather, a boundary peak and British Columbia's highest point, had left their camp on the north shore of the bay shortly before, flying to Juneau a day early because of some weather apprehension of their RCAF pilot.

In a violent break like that of July 9 the shearing motion spreads rapidly outward through a complex system of rock faults. The Fairweather break reached the surface in a still-unexplored pattern of cracked granite and slumped earth reaching more than 150 miles through mountainous uplands and glacier-filled valleys—all the way from Icy Strait north to the vast Malaspina Glacier that spews down from the heights of the Cook-Augusta-St. Elias mountain massif. A wild upheaval exploded over the land in what seismologists were soon to rate one of America's greatest earthquakes. Boats at sea felt unimaginable hammering from the water. One fisherman 12½ miles off Icy Point reported that despite a smooth sea he felt he was riding on a big explosion—the worst experience he ever had. Another said it felt like jumping 12 feet out of the water.

The peaks of the Fairweather Range shivered visibly all the way to the summit more than 15,000 feet above the sea. Avalanches slowly began their descent amid great clouds of dust and flying snow. Some thought it looked like the end of the world. A whole mountainside came down at Point Astrolabe. The Swansons and the Ulrichs in Lituya Bay rose in alarm to gaze in unbelieving wonder and terror. Swanson and his wife later insisted that the terminal ice mass of Lituya Glacier rose into view from behind a headland up the bay, with great masses falling from its face, and then fell majestically into the water, creating a wave that went over the whole headland. It then caromed down the bay, scouring the shores of their trees, obliterating the mountaineers' campsite, overrunning Cenotaph Island and its lone cabin, and killing the Wagners and all but killing the Swansons in a surfboard kind of plunge of their two boats across 40-foot-high La Chaussee Spit to destruction in the sea outside—a wave of such improbability as to strain the credulity of later investigators, and to remain a scientific puzzle.

A hundred miles of alluvial soils in the coastal lowlands shook and danced, giving birth to uncounted sandboils, sulfur stench, 20- to 30-foot geysers, and great cracks, one of which completely swallowed a truck where it stood beside the Akwe River near Dry Bay. Several men, thrown to the ground in a cabin on nearby East River, managed to scramble out before its collapse, but found their escape through the heaving landscape only with great difficulty. In Yakutat Bay the Williams couple in their boat off Point Turner gasped when the outer part of the point seemed to rise 20 feet in the air, then collapse in a welter of churning waters that swallowed Tibbles and his wife and

Mrs. Walton forever. Virgil Mann's geologists may well have been wishing they had moved earlier to the cabin on Cenotaph Island, farther from the center of the disturbance. The Canadian mountaineers strolled the streets of Juneau a day ahead of their expectations, unaware of the debt they owed their pilot for his weather worries. The beginnings of panic in Juneau's gently swaying Capitol Theater were stilled by the authoritative command rising above the soundtrack, "Keep your seats!"

Public consternation and damage occurred over a 400,000 square mile area reaching such scattered places as Anchorage, Cordova, and Ketchikan. In Petersburg people ran to the streets. Landslides were seen in Warm Springs Bay, 100 miles south on Baranof Island. The fishing village of Pelican on Chichagof Island saw several hurt in the falling of objects, and heavy losses of equipment. One hundred miles to the east, near Juneau, a chimney toppled, bells rang, and a sandbar was seen "shaking like jelly." The Alaska Communications System had six cable breaks due to some kind of submarine upheavals in the Haines-Skagway area, and one at Wrangell, distant a surprising 250 miles from the quake. At Seattle the Coast and Geodetic Survey's strong-motion seismograph in the Federal Building recorded more than an inch of back-and-forth motion in the foundations of the city, and 20 musicians in an orchestra shell floating on Seattle's Green Lake, more than 1,000 miles from Fairweather's broken rocks, were shaken by a 5-minute series of oscillations—possibly an alltime distance record for human sensing of an earthquake. Without doubt the most remote commotion of all was created when the Survey's tidal wave warning system went into operation after a minor sea wave was reported from the Sitka tide-gaging station. A public warning of a possible tidal wave in Hawaii, though later seen to be a false alarm, caused waves of excitement and traffic jams as people fled low-lying areas. Of more lasting concern was the difficulty, back in Alaska, of salmon seining through masses of dead halibut, cod, and octopuses, their carcasses drifting among uncoun- ted stripped and barkless logs, masses of ice, and other debris which cluttered the area for days.

At the moment of Fairweather's rupture the springing of the torn rocks to less strained positions sent forth waves of vibrant motion that traveled the surface layers and the deep interior of the entire earth, arriving in due time at successively more distant seismograph stations, where delicately suspended instruments were set into responsive swinging. The floating orchestra pit at Seattle was in effect a giant earthquake detector—possibly the hugest on record. The waves included pressure variations of the type of sound waves in the air, sidewise jerks like the kink that travels a tightrope when it is

struck, and still others. They traveled numerous paths, some by reflections within the earth, so that their arrivals at particular points made protracted and complex patterns on the recorders—patterns incomprehensible to anyone but skilled seismologists, but when correctly interpreted very revealing indeed. In fact, they carried within their complex patterns extremely good indications of the distances the waves had come from their origin.

Not many seismologists are aware immediately of a distant shock, because the typical seismograph recorder, which photographs the motions of a tiny spot of light, works in a dark chamber to make a record that is developed but once a day. (The favorite news story about the needle being knocked off the record is more expressive than accurate—it reflects an obsolete process of scratching a line on a paper that has been blackened over a smoking lamp, a method in use before seismologists learned to make electrons do their work.) Modern stations also use electrically driven recorders that draw the line visibly with ink, sometimes even hooked up to alarm devices; however, such elaborate apparatus is not yet in universal use.

In the case of the Fairweather shock, it was night in North America and most American seismologists were off duty or asleep. The visible recorder in the Washington office of the Coast and Geodetic Survey went into violent action at 1:24 a.m., the first waves having taken 7 minutes and 58 seconds to travel the 2,800 miles at an average speed of almost 6 miles a second, but it worked unobserved for no one was there. Nor were witnesses present at other leading observatories—Weston College, Harvard, Fordham, Columbia, St. Louis University, and many others. But the quake did not lack notice. Hardly had the groundwaves arrived when the Survey's observers at Tucson, Sitka, and Honolulu, in concert with cooperating seismologists on the Berkeley campus of the University of California and at Caltech's Seismological Laboratory in Pasadena, were rushing to their visible recorders to see what had set their bedroom alarms to ringing. Together they constituted a ready force for warning action in the face of a possible Pacific tidal wave, generated by the rising or sinking of an extensive segment of the ocean floor in an earthquake. This dramatic and often disastrous event, technically a seismic sea wave, is known more conveniently by the Japanese term "tsunami," the literal meaning of which is "wave-in-a-bay." Lituya's wave of 1959 was therefore a true tsunami, and, as it turned out, not a seismic sea wave.

As is the way with seismologists the world around, a widespread exchange of station reports and interpretations had begun by morning. In the coordination and analysis center of the Coast and Geodetic Survey, plotting of the distance readings indicated where the

break had been—under Mount La Perouse, 58.6° north of the Equator and 137.1° west of the Greenwich meridian. William Stauder, a Jesuit scientist then working at Berkeley, plotted a position slightly different—near the coast at Point Astrolabe. It cannot be said which most nearly fits so deeply buried an event. The violence of the jiggles recorded on the photographic paper showed how great was the energy of this quake. Standard instruments at Pasadena and Berkeley showed it to be a true giant with a magnitude of 8.0 on the energy rating scale devised by Caltech scientists Beno Gutenberg and Charles Richter. The highest magnitude ever observed was about 8.7 on the same scale, a figure representing the greatest amount of energy, according to the Japanese seismologist C. Tsuboi, that can be stored in stressed rocks and released in a single quake. This release of energy is estimated to equal some 100,000 Hiroshima-type atomic explosions, though it is of course far less concentrated in its effects. One earthquake of such top-level magnitude was that of August 15, 1950, which triggered tremendous landslides in the high Himalaya of the China-Burma-India border area, and ultimately produced widespread floods in the Assam tea gardens. Another occurred in January 1906, in a remote part of Colombia, in South America. Neither killed many people, but had either area been populated, the death toll would have been enormous.

The public importance attached to an earthquake is understandably keyed to the damage and casualty rolls, rather than to its scientific evaluation; hence the great earthquakes of history are not always the strongest. For instance, the Santa Barbara and Long Beach tragedies of 1925 and 1933, both scientifically minor California shocks, will be remembered in company with their stronger fellows, such as the 1908 devastation of Messina, Italy, in which 100,000 died, and the Tokyo disaster of 1923, which destroyed an unbelievable 576,000 buildings in an earthquake and fire which claimed almost as many lives. Such a scientific front-rank event as the 1906 Colombian shock escaped public notice, and it is safe to say that the great Fairweather shock, which killed five people (and would have been forever infamous had it struck a large city) has passed long since from public notice.

It will not soon be forgotten by seismologists, however, who now know it to be among the four strongest shocks in the history of North America. In 1811 the river-bottom country about New Madrid, Mo., shook and shivered, and visible waves in the ground, like those of the sea surface, startled unbelieving witnesses. Reelfoot Lake was created when 30,000 square miles of the land sank, some of it as much as 15 feet. The motions were felt by people throughout more than 2 million square miles, as far away as Boston. Seismologists say it was one of the greatest in all history. In 1886 the famous Charleston, S.C., quake

destroyed 100 buildings at a cost of \$5.5 million and left cracks in practically all masonry structures—cracks now proudly preserved by the owners of surviving houses as a kind of social distinction. The most famous, if not the strongest, of all American quakes was certainly the one that rocked San Francisco on April 18, 1906. Broken water mains contributed to the wide spread of a fire which caused the larger part of the 700-odd casualties and the half-billion dollar damage toll. San Franciscans insist on the distinction—there seems to be a question of civic pride in these matters—between the quake and the resulting fire. This is the only one of the three quakes to have a Gutenberg-Richter rating based on modern instrumental readings. It was 8.25, just barely ahead of the Fairweather shock.

The Gutenberg-Richter scale has no relation to the number of people killed or houses wrecked but there are other types of rating scales that have. Seismologists call them intensity scales; instead of rating the energy of a quake, they furnish an evaluation of its local effects at a given place regardless of its distance from the shock. These scales are concerned with such things as public alarm, the falling of objects, cracking of plaster, destruction of buildings—even cracks in the ground. Such effects excite people, of course, and newspaper stories deal with them pretty much to the exclusion of such prosaic facts as their energy. The intensity scale most used in America is the Modified-Mercalli scale, from a rating system devised by the Italian Mercalli. Its highest grade is 12, an ominous number that signifies total destruction. Evidence is lacking for the explicit intensity rating of the Fairweather shock; had such ground movements occurred in a built-up locality, however, there can be little doubt that the destruction would have been essentially complete.

Seismologists point to the fact that neither the New Madrid nor the Charleston earthquake occurred in an area known as dangerous, although nearby parts of South Carolina do, in fact, exhibit occasional minor shivers. This supports the standard warning of the profession that no place on earth can be said to be really safe from damaging shocks. The 1906 event in California, on the other hand, was in a highly seismic area, directly on the well-known San Andreas Fault, a source of recurring shocks throughout a notorious past, and probably of many more to come. The Coast and Geodetic Survey has long made periodic repetitions of geodetic measurements in the vicinity of the San Andreas, finding slow movements of the land, which are proceeding, in fact, on a truly grand scale—a great region west of the San Andreas is slowly creeping northwestward in relation to the country east of the fault. This distortion amounts to some 2 inches a year, certainly enough in the course of centuries to place great stresses in the crustal rocks. Historical records are too short to

indicate with any certainty what patterns of earthquake recurrence may exist on the San Andreas, although some geologists have said that great earthquakes may occur somewhere along that zone of weakness at about 50-year intervals. This does not threaten San Francisco with a great jolt at any specific time, for the fault is very long—it extends from an origin in the Gulf of Lower California northward through the San Francisco area to an eventual disappearance in the sea off northern California—and an earthquake could occur anywhere along its length.

The San Andreas, for all its length, is but a detail in one of the world's great belts of seismic activity—an arc extending around much of the Pacific Basin, from the unstable western mountains of South and North America, through southern Alaska where lie the Fairweathers and Lituya Bay, through the Aleutian Island chain, past Japan and the Philippines, and on southeastward toward New Zealand. Some of the western Pacific areas on this arc show the greatest concentration of heavy shocks recorded anywhere in the world. The whole great arc is what is known as an orogenic zone—an area of geologically young and changing forms characterized by high mountains which have not had time to erode down as have the more mature Appalachians, and deep ocean trenches not yet filled with sediments. The progressive changes are typified by the crustal migrations shown by the geodetic surveys in California, and by the upward growth of southeast Alaska's mountains—movements that become earthquakes when the rocks fail to yield sufficiently fast and end by breaking.

In the California quake of 1906 two mountains near San Francisco moved 10 feet farther apart at one stroke, and along the San Andreas the horizontal slipping in that one quake amounted in places to no less than 21 feet. Roads, fences, even rows of orchard trees were offset in broken lines where they lay across the fault. In another quake along the southern reaches of the great fault, a unique territorial problem was presented when the United States border with Mexico shifted position. There is geological evidence that these movements have been repeated so many times that their total accumulation along the San Andreas now amounts to as much as 350 miles or more. This probably took 100 million years, which, though long in human terms, is but a brief period in geological time.

In parts of southeast Alaska, particularly north of Icy Strait, the upward growth of the land has been monitored for many years. Long sequences of tide-gage observations east of the Fairweathers have shown how fast this is. At Haines in Lynn Canal the land has risen out of the sea some 5 feet in 60 years; at Skagway and at Juneau the emergence has amounted to 3 feet in 50 years; and an engineering firm found indications of nearly 6 feet of rise of the land in Excur-

sion Inlet, which runs north out of Icy Strait, since the date of a patent survey made in 1909. These changes are unspectacular except when they occur as earthquakes—then the news circuits carry excited tales of events like those of July 9, 1958, at Lituya Bay. Don Miller, of the Geological Survey, and Don Tocher, of the University of California, in a preliminary search of the most accessible reaches of the Fairweather Fault since the 1958 quake, found horizontal displacements of $21\frac{1}{2}$ feet accompanied by new escarpments $3\frac{1}{2}$ feet high. The land west of the fault moved northwestward, as it does in the case of California's San Andreas, suggesting a kind of grand-scale system at work. These movements may seem dramatic but they are minor compared to the dislocations of the Yakutat Bay earthquake of September 10, 1899—an earlier step in the long series of readjustments going on in the growing Fairweather Range. Yakutat Bay is a story in itself—the subject of extensive field examinations by the Geological Survey in the years following the shock and of bulky technical reports on the findings. The almost unbelievable fact is that the shores of Disenchantment Bay, an upper arm of Yakutat Bay, rose no less than 47 feet 4 inches out of the sea in that convulsion, the greatest known faulting ever to occur in a single quake. Lacking previous tide-gage records in the locality, many kinds of evidence had to be found to verify this startling observation, including traces of elevated beaches, old high-water marks on the rocks, and telltale effects on the vegetation. The best evidence, found some years after the event, was the remains of dead barnacles far out of the water. Vertical measurements between the highest live barnacles to be found and the highest dead barnacle shells proved the point beyond doubt. What a prelude this was to the incredible events of July 9, 1958.

These events received prompt attention by seismologists, geologists, geodesists, and hydrographers. T. Niel Davis, of the Geophysical Institute of Alaska, was soon there with a plane for view photography. By July 17 the Coast and Geodetic Survey had Merlin Natto on the scene with Air Photo Mission 701 to investigate topographic changes. The Survey's ship *Pathfinder* under the command of Ira Rubottom arrived on September 16, en route from a surveying assignment in Bristol Bay, to obtain preliminary soundings of the underwater changes.

The upheaval of Point Turner, which had swallowed Mrs. Walton and the Tibbles couple so abruptly, saw the utter disappearance of the harbor light and of some 100 to 150 feet of the south end of the island, cut off as if by a great cleaver. Compared with surveys made in 1942, 800 feet appeared to be gone, but much of this was probably the effect of erosion of the sandy deposits during the years. At any rate the land upon which the strawberry pickers had stood just before



1. Effect of great wave, Lituya Bay, Alaska. Promontory cleared of trees to estimated height of 1,800 feet



2. View of Lituya Bay, showing the wave scour along the shore

the shock was now gone, and in its place there swept back and forth with the tides some 90 feet or more of water—more than enough to float the largest ship in existence.

Topographic changes and differences in water depths were found in profusion. As if to balance the loss of Point Turner, 100 feet of the north end of Khantaak Island was found to have disappeared. The *Pathfinder* found sea bottom risen in places as much as 78 feet and sunken equally in others. Extensive portions of the shores of Yakutat Bay were gone, fallen into the sea with deep water flowing in their places. Such circumstances invalidate existing maps and charts, forcing the Coast and Geodetic Survey to plan comprehensive new surveys of both land and sea in its effort to keep up with this corner of the changing world. Geologists and seismologists are sure to study the area for years to come.

While Yakutat Bay rearranged itself, the small fishing and commercial port from which the bay takes its name had its own share of excitement. Bridges, docks, and warehouses were damaged. The ground cracked near Mrs. Walton's cannery. Objects fell in profusion, and a water tank collapsed in a twisted pile. The harbor currents flowed the wrong way past the waterfront, and the so-called Millpond near the airport sloshed violently. The ramp rose and fell like the waves of the sea, while 1,100 helium cylinders, which had been stacked in neat array, all fell to the south as though bowing toward the origin of all the commotion. Virgil Mann reported a similar freak of nature from Lake Crillon, where whole stands of spruce trees had 15 feet of their tops broken off and thrown head down toward the southwest.

But the most violent effects were in Lituya Bay, only 15 miles from the source of all the trouble. Six and a half miles long and two miles wide, with deep water and good anchorages, it is the only refuge—one ordained by nature to be precarious, at that—in the long stretch of forbidding coast between Cape Spencer and Yakutat Bay, and it has consequent interest for mariners seeking shelter from the rough seas of the Pacific.

Lituya Bay was discovered in 1786 by the French explorer Jean François de Galoup, Comte de la Perouse, in the course of a voyage of discovery with the vessels *Astrolabe* (named for a traditional astronomical instrument) and *Boussole*. He named it "Port des Français," but early Russian charts showed it as "Altua Bay," and the whalers of the 19th century knew it, for obvious reasons, as "Frenchman's Bay." La Perouse described it as a place of great beauty by reason of the surrounding tree-clad hills and the majestic backdrop of the snowy Fairweathers. It had sandy shores abounding with strawberries, and the glaciers at its head discharged small sparkling ice-

bergs suitable for replenishing the mariners' iceboxes. Lituya's inner end is crossed like a T, with Lituya Glacier emptying into Gilbert Inlet on the north, and Crillon Inlet and Glacier at the opposite end of the T. The corners where the inlets meet the bay are guarded by two mountains like gateposts, and the opposite shore on the east is a wall rising steeply toward the main mass of the big range. This natural amphitheater, in which the normally still waters are walled about by high green-forested slopes and the towering faces of the glaciers, is a secluded place of cathedral-like solemnity and grandeur.

Lituya may seem like a miracle of nature, but men have learned that it has a harsh and cruel aspect. For one thing, it is plagued by a narrow and difficult entrance, nearly closed by the spit known as La Chaussee because it looked to the Frenchmen so like a causeway or dike. The two small vessels of La Perouse, on first approaching, found themselves sucked into a veritable sluiceway where the tide flooded past sunken rocks through an 80-yard passage. After they whirled, completely out of control, into the calm water of the bay and came to rest he wrote in his journal, "In my 30 years of navigation I never saw two ships so near destruction." Later mariners have learned of the dangers lurking in these powerful currents, often made worse by the breaking of storm waves and terrifying tide rips, so they try to make the passage during the brief periods of slack water between the ebb and flow of the tide.

La Perouse, it turned out, was not to escape disaster after all. While awaiting good weather he sent out small boats to survey the bay, 3 of them being seized in the ebb current and swept out the entrance through high combers, where 2 were swamped with the loss of 21 of his men. On his chart there was shown a low, rounded island near the middle of the bay, where he erected a monument to the memory of the lost sailors. The island has long borne the name Cenotaph. Subsequent history records a long tale of ship losses and drownings in Lituya's difficult entrance, of which La Perouse's was but the first.

The chart also showed two Indian villages on the south shore of the bay, of which no trace exists today. It is not even known when they were destroyed, but it probably occurred during a great wave in 1853 or 1854—there is an old tale relating how several sea-otter hunters survived the disappearance of their villages about that time by being at sea in their canoes. This, then, is the other of two evil aspects of Lituya—the lurking menace of unpredictable waves that wipe villages off the earth, that pick up anchored boats and throw them over La Chaussee Spit, that sweep mountainsides clean of their forests.

There must have been many great waves in the unrecorded history of Lituya. One of them, in 1936, we know well from eyewitness

accounts. At that time Jim Huscroft had lived on Cenotaph Island, engaged in fishing and prospecting, and he had built himself a cabin 50 feet above the water on the southwest side of the island. He had a companion that year of 1936, with whom he had salted down 50 barrels of salmon, storing them temporarily in a shed near the cabin. Huscroft was getting breakfast on October 27 when a roar was heard, "like the drone of 100 airplanes at low altitude," followed by a wave sweeping down the bay. The two scrambled for safety on higher ground, saving themselves only to see their season's catch of salmon swept away and the cabin flooded. Its time had, however, not yet come, for there it was destined to stand for another 22 years awaiting an end in the greater, higher wave of 1958, 1 day before Professor Mann was to have moved in with his men.

At least one other great wave is known through clever interpretations of nature's telltale signs. The Geological Survey's Don Miller, a highly respected specialist on Alaskan geology and one of the first investigators of the 1958 wave, had noted some years ago that the trees about the shores of the bay grew in remarkable zones of uniform age, bordered by trim lines separating zones of different ages. These trim lines he traced along the flanks of the hills bordering the bay, finding in them convincing evidence of successive scouring of the slopes by wave inundations at different times and heights. Miller found two definite trim lines, the lower having a maximum height of 400 feet in one arm of the bay and lesser heights toward its entrance, and the other generally higher one with a greatest altitude 2 miles from Lituya's inner end. It was clear that the younger trim line was created in 1936 by the wave seen by Huscroft. The other, according to tree-ring studies, must have been in the winter of 1853-54. Neither of these dates has a record of any important earthquakes near Lituya; therefore these inundations, whatever their cause, are not necessarily seismic sea waves. Miller presented these facts at an annual meeting of the Geological Society of America in Seattle during 1954, finding skepticism, despite his compelling evidence, that sea waves could wash hundreds of feet high on a mountainside. The doubts were shared by oceanographers and hydrographic surveyors. They thought they knew the sea, but they little knew the power of Lituya.

Miller had discussed possible causes of such waves, finding unlikely the release of an ice-dammed lake, or the fall of glacier ice into the bay. He found the idea of earthquake upheavals under the water a tempting idea, but noted the absence of any earthquake records for the years concerned. The speculation was made even more imaginative when some of Professor Mann's men later suggested that the 1958 wave, which followed a very violent quake indeed, might have

been caused by an opening of a cavernous crack in the sea floor, sucking in the water only to close again with a violent squirt up over the hillsides. This, however, seemed improbable.

From later study of Natto's aerial photographs and survey records it is clear that many great landslides occurred, falling down the mountainsides from heights as great as 3,000 feet, and that tremendous masses of ice fell from the towering face of Lituya Glacier. Whether triggered by an earthquake as on July 9, or by other causes, such great volumes of material suddenly dumped in the confined waters of a bay can apparently raise the water level enough to generate a wave. On July 9, 1958, there was caused such a wave which may have been 50 or 100 feet or more in height—a wave that sloshed back and forth in a maelstrom with energy enough to send its waters high on the banks, take down trees and earth, and to make Miller's trim lines understandable after all. It ended by sweeping down the bay, leaving a trim line of varying height according to the configuration of the hills, but apparently as high in places as 500 feet. On the way it scoured the slopes of Cenotaph Island up to 165 feet, and flowed through a low point on its ridge, incidentally removing every recognizable object at the site of Huscroft's old cabin. Even at the bay entrance, after a 6-mile trip, it still had force enough to break loose the two anchored boats and lift them over the spit and completely out of the bay.

The wave heights of July 9 were immediately seen to dwarf those that had left Miller's old trim lines. All the viewers in the days following the wave exclaimed in amazement at the appearance of the western mountain at the corner of Gilbert Inlet. Where it had formerly been tree clad all the way down to the shore, its steep bulwark now stood starkly bare to a height of more than 1,600 feet. The rocks seemed to be washed clean—did this mean that the wave had climbed to the incredible height of 10 Niagaras? There were those, including the authorities Miller and Tocher, who thought so from the first, but mass skepticism met their claim, and the controversy is not yet stilled. There was most certainly a landslide on the western mountain, and it is easy to point out that it alone could have denuded the mountain, but this easy explanation falls before the opinion of the Survey photogrammetrists, experts at photointerpretation and the appraisal of land detail revealed by stereographic plotting instruments. Concluding the compilation of a new topographic map from Natto's photographs, they expressed their unanimous conviction that the water did reach a height somewhere between 1,200 feet and the top of the bared mountainside area. It was apparent to them that nothing but an actual flood could possibly have scoured the folded and creviced rocks so thoroughly clean of every bit of dirt and

debris—certainly not the landslide alone. Then, too, there are the eyewitness reports of the survivors of the wave.

It seems that the Lituya Bay wave of 1958, a true tsunami in the original sense of "wave-in-a-bay," unbelievably but in all probability threw its foaming crest higher than any wave ever before known to man.

Eyewitness stories of the Lituya events come from the Swansons and from Howard Ulrich. Bill and Vivian Swanson, occupants of the *Badger* during her mad flight across La Chaussee Spit in company with the ill-fated Wagners, somehow managed to get clear of the wreck in an 8-foot punt, undergoing exposure and fright as well as loss of their worldly possessions, before their rescue by a fisherman named Graham in the trawler *Luman*. They were quickly flown to Juneau in a rescue plane and, after a short hospital rest, were able to describe their experience. They were sure they had seen the glacier riding high into sight from behind the western mountain, followed by a great wave of water washing over its steep face. During the following wild ride across the spit they believed they were 100 feet high, for there had been trees on the spit, and they were above them. They looked down on rocks as big as houses. They were incredulous and deeply thankful to be alive.

The story told by the other survivors, Howard Ulrich and his son, will probably be unmatched for a long time to come. In a vivid account published in *The Alaska Sportsman* Ulrich tells how they entered the bay on the last of the floodtide for rest after a day of poor fishing. He anchored the *Edrie* in a cove on the south side a mile or so inside the entrance, and after supper he and Sonny went to sleep, only to be awakened by violent motions soon after 10:15. Dashing to the deck, Ulrich beheld the writhing and twisting of the high peaks and the clouds of dust and flying snow about their summits. Petrified, he watched for 2 minutes or more until his attention was attracted to a new sight. There was a gigantic wall of water which he thought to be 1,800 feet high erupting against the western mountain, then coming down the bay, cutting a swath through the trees on the summit of Cenotaph Island, backlashing against the eastern shore up to a height of 500 feet, then heading for the *Edrie*, now a wall of water 50 feet high.

Suddenly he realized he had to move. Cursing himself for delaying, he got a lifejacket on Sonny, then somehow got the engine going, but he was unable to heave the anchor in time. Just before the water struck he veered the chain to its end, hoping to slip it, at the same time maneuvering the *Edrie* to face the wave. As she lifted to the swell the chain tightened and snapped, its short end whipping up and winding around the pilothouse. The boat was swept, completely

out of control, over what had been dry land a moment before. By now Ulrich remembered his radio. Shouting into it, he made the international voice-radio distress call, "Mayday, Mayday—*Edrie* in Lituya Bay—all hell broke loose—I think we've had it—goodbye!" The wave, however, changed course and bounced off the shore, allowing Ulrich, with strenuous efforts and certainly with superb seamanship, to get his boat under a kind of control. He now began devoting himself to evading huge chunks of churning ice, any one of which could have made kindling wood of the *Edrie*.

The next problem was to get out of the bay through its turbulent and tricky entrance—a passage bad enough at the height of the ebb, not to speak of the wild conditions of that particular moment—for the remotest chance of getting out looked mighty good to Ulrich just then. He tucked pillows about Sonny and told him to hang on for dear life. A stroke of luck now appeared in the form of a helping hand. A fellow fisherman had become aware of the situation and was taking station outside the channel in his boat *Theron* to give Ulrich a guiding mark for running the swift ebb tide. Bracing himself, Ulrich headed for the biggest gamble of his life. Ages later, it seemed, he was out. Three giant combers had broken over the tiny pilothouse, but the *Edrie* was sturdy—she shivered but she came through. Howard Ulrich does not know whether he will ever enter Lituya again, but the chances are he will. Seamen are like that.

Hailstorms and Hailstones of the Western Great Plains¹

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[With 8 plates]

DURING the evening of June 27, 1959, the region of Grand Island, Nebr., was ravaged by a very severe hailstorm. The intensity of the storm, including wind, lightning, rain, and hail, was of the degree which has given this area of the Great Plains the dubious reputation for having some of the worst hailstorms in the world.

The storm displayed its greatest intensity between the hours of 2120 and 2200 in the region immediately north of Grand Island. The losses, estimated at greater than \$5 million in the Hall County area alone, consisted of damage to crops, buildings, homes, automobiles, and aircraft. So many windows were broken that all local supplies of glass were depleted, requiring emergency shipments from Omaha. The windshields of hundreds of automobiles were shattered as shown in plate 1, figure 1. A newly reconditioned Convair aircraft parked at the Grand Island airport was dented and windows were broken as shown in plate 1, figure 2. According to local news reports, the anemometer used by the Federal Aviation Administration was blown away as it recorded a wind velocity of 80 miles an hour. Plate 2, figure 2, illustrates the damage done to a 3-cup anemometer at the airport, and plate 2, figure 1, some of the hail remaining on the ground the next morning.

The most damaging hail was reported along a strip 5 miles wide and some 30 miles long. The storm was reported to have developed so quickly and moved so fast that there was insufficient time to give adequate warning. The hail phase of the storm developed between Ravenna and Cairo, and moved rapidly eastward through the Boelus area, going almost to Central City. At Boelus, a tornado was reported.

Much damage occurred in Cairo, Nebr., with most of the broken

¹ Reprinted by permission from *Nubla*, vol. 3, No. 1, Verona, Italy, 1960.

windows being on the west side of buildings. At Grand Island, the storm caused major damage on the north side of the city with the southern area having little difficulty.

Although local reports suggested that the storm developed suddenly about 20 miles west of Grand Island, an examination of field observations from several sources shows that a violent storm developed in the broad trough in the lee of the front range of the Rocky Mountains which remained after a cold front passage on June 26. At about 1300 on the 27th, large cumulus clouds began building 20 miles west of Sterling, Colo. [1].² These initially formed as single cells, but by 1450 had moved eastward and merged into an intense 80-mile squall line stretching from Akron to Julesburg, Colo. At 1510, a pilot, flying at about 12,000 feet east of Sterling, reported his AT-6 aircraft was showing 150 knots airspeed with the throttle closed. An observer at Haxtun, Colo., reported roll clouds dropping to the ground and back up to the cloud base at 12,000 feet within intervals of less than a minute. Very little hail occurred in northeastern Colorado with the exception of a zone of heavy hail damage 25 miles to the west of Sterling. This occurred in the early afternoon. The wind at Sterling, Colo., at ground level reached a maximum of 75 miles an hour during the squall-line passage at about 1400. From the Haxtun-Holyoke area, 26 farmers called the Sterling field station to report the worst storm situation they had ever seen. If a line is drawn from the zone north of Fort Morgan and west of Sterling, where severe hail damage was reported early in the afternoon of the 27th, to the area of heaviest damage which occurred at 2145 north of Grand Island, Nebr., the distance is 250 miles, and the storm propagation at ground level shows an average rate of movement of 28.5 m.p.h. The direction of propagation closely coincides with the winds at 500 mb. which showed a velocity of 40 to 45 knots during this period.

During the period 2036 to 2242, very intense radar echoes from the Grand Island area were observed at Schilling Air Force Base near Salinas, Kans. Two strong echoes passed across the area where the most severe hail damage occurred. The largest echo showed a hooklike protuberance and coincided with the area of highest intensity and damage. During the most intense hail period it had a diameter of about 20 miles.

This pair of echoes moved at a speed of about 45 m.p.h. with an azimuth of about 255°. This was the wind velocity and direction shown on a 500-mb. chart of 1800 c.s.t. Another radar unit at Offutt Air Force Base near Omaha showed the same echoes and indicated that this portion of the storm complex comprised the southern extremity of an extensive storm system, which by 2157 contained a line of echoes over 100 miles long whose major axis was oriented with an

² Numbers in brackets refer to list of references at end of article.



1. Hail damage to automobile parked at Grand Island, Nebr., evening of June 27, 1959. (Frontier Airlines photograph)



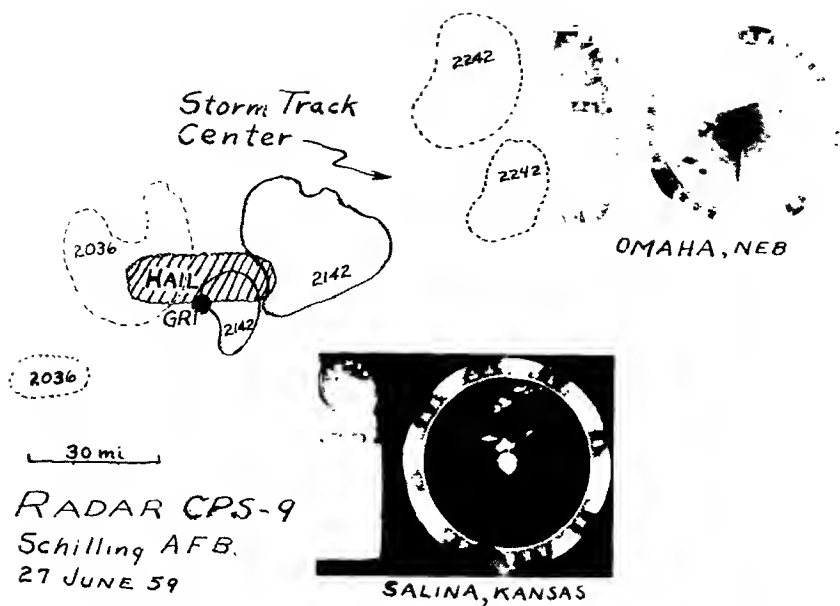
2. Hail damage to Convair aircraft parked at Grand Island Airport, June 27, 1959. (Frontier Airlines photograph.)



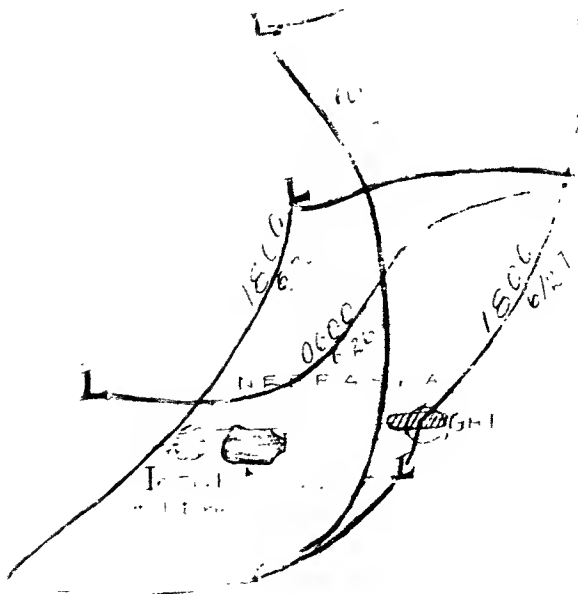
1. Hail remaining on ground at Grand Island, Nebr., morning of June 28, 1959. (Frontier Airlines photograph.)



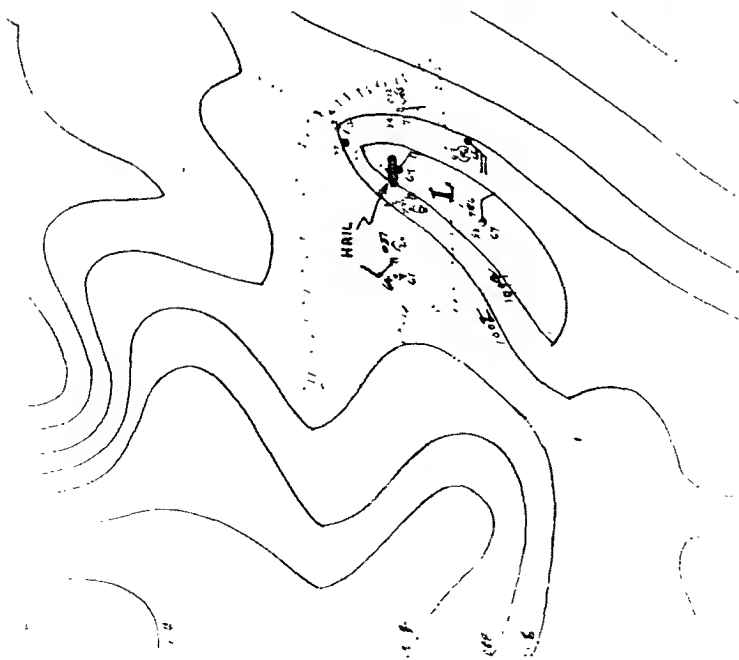
2. Hail damage to 3-cup anemometer located at Grand Island Airport, June 27, 1959 (Frontier Airlines photograph)



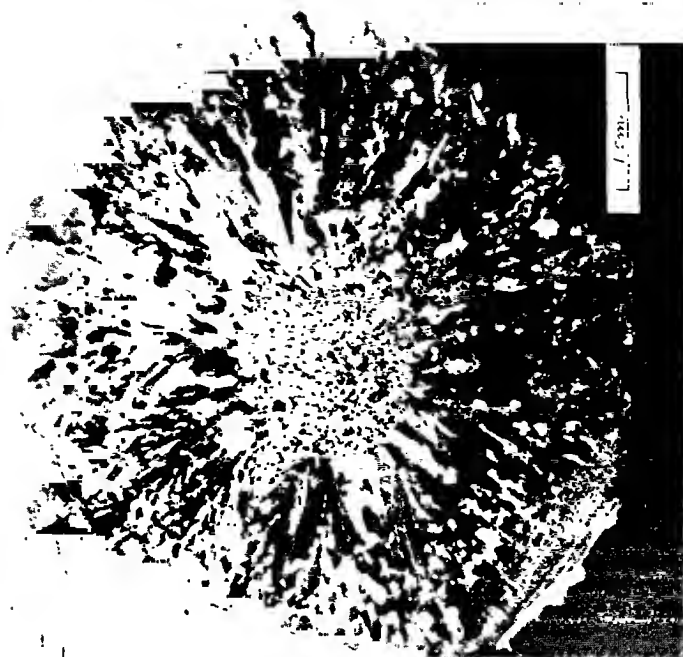
1. Radar echoes of hail cells and their geographic relationship to the hail damage zone
June 27, 1959.



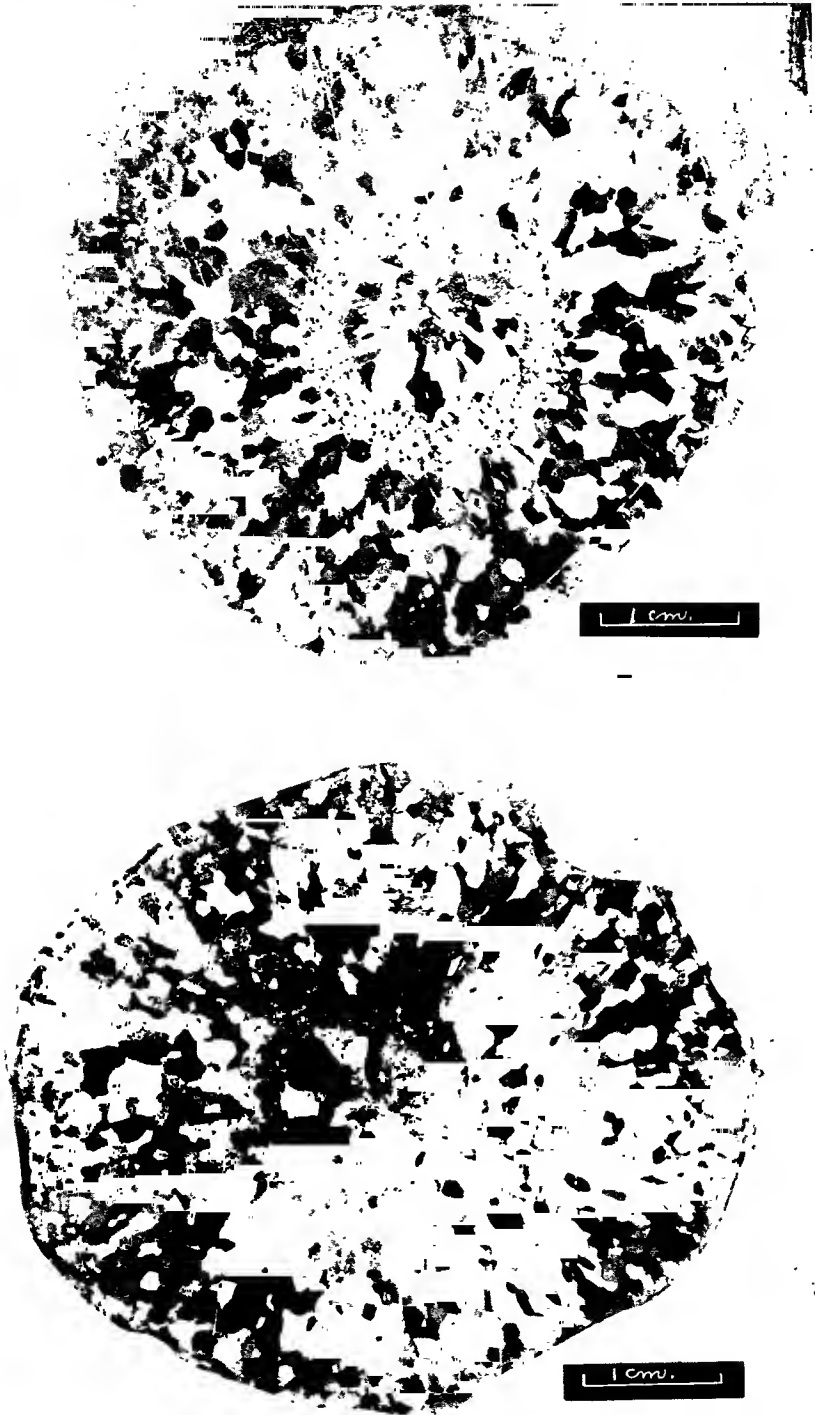
2. Position of front and low pressure on wave moving slowly eastward, June 26-28, 1959.



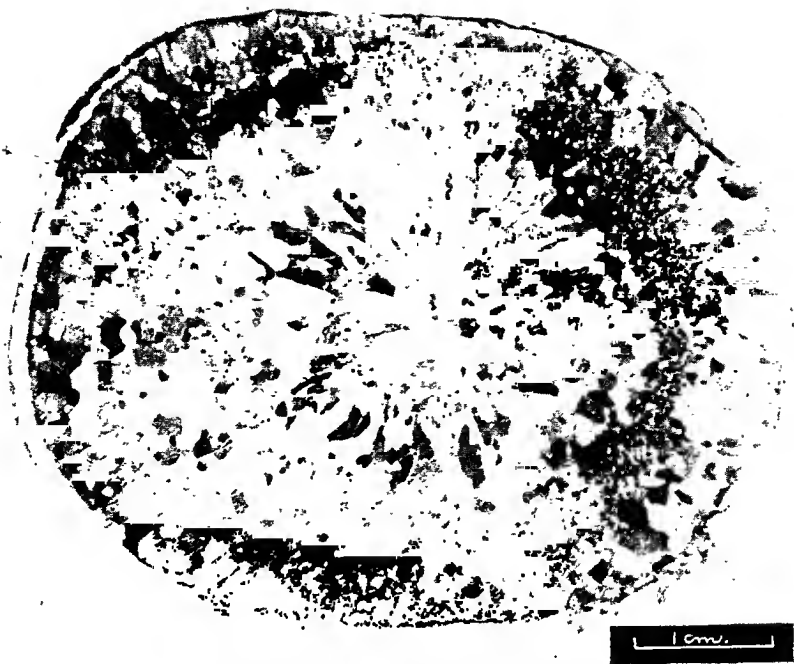
1. Surface position of low in relation to zone of damaging hail at 2200 CST, June 27, 1959.



2. Elongated crystals in a large hailstone.



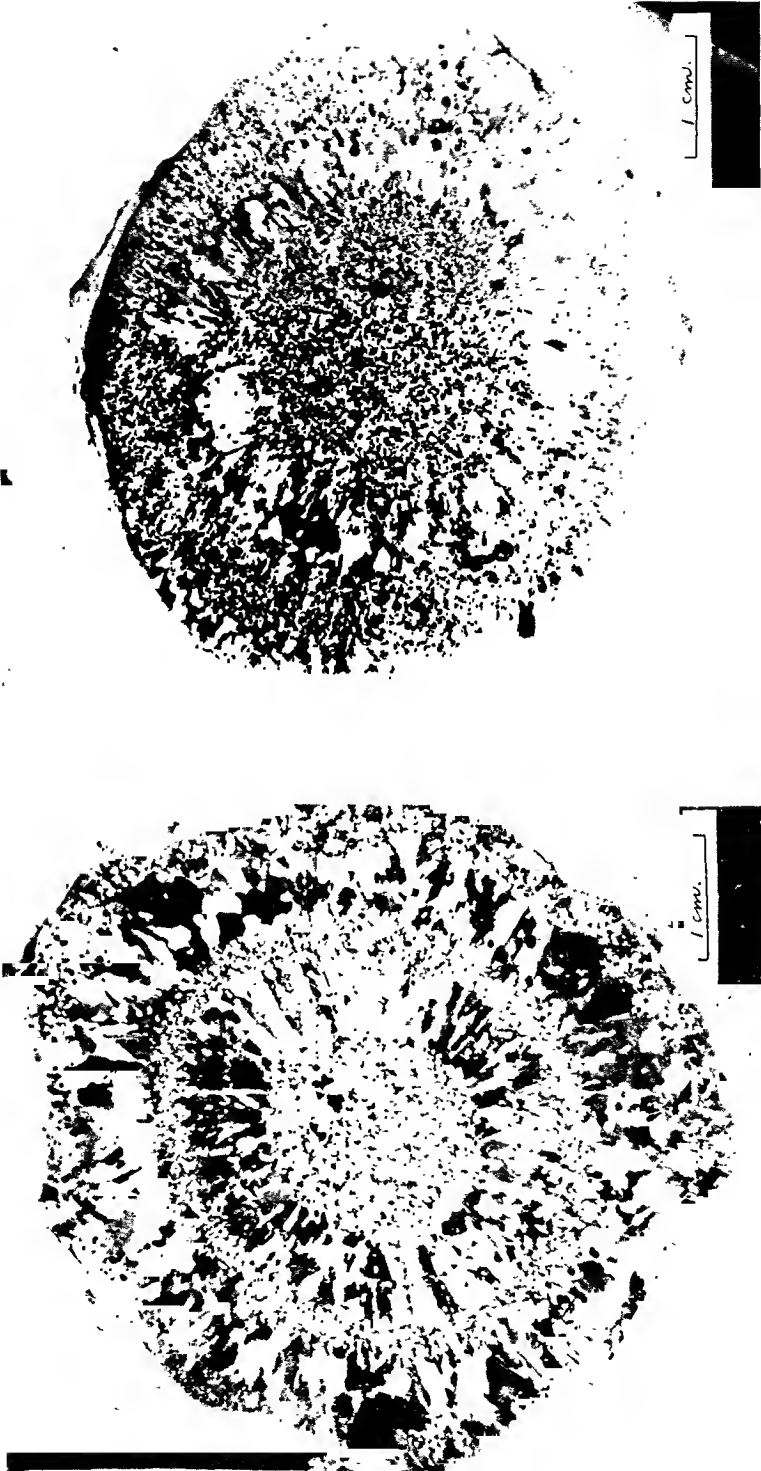
Typical cross sections of hailstones from Grand Island, Nebr., storm of June 27, 1959.



Typical cross sections of hailstones from Grand Island, Nebr., storm of June 27, 1959.



Variations in hailstone cross sections from a single storm, St. Louis, Mo., May 18, 1960.



Variaions in hailstone cross sections from a single storm, St. Louis, Mo., May 18, 1960.

azimuth of 250°. The radar photos and their geographic relationship to the hail damage zone is shown in plate 3, figure 1.

1. ORIGIN AND FEATURES OF THE STORM

During the latter part of June, the area east of the front range of the Rockies experienced a series of severe hailstorms. On June 26, the leading edge of a cP air mass moved out of Wyoming with the center of the low over the Wyoming plains near Rawlins early that morning. This low moved northeastward during the next 18 hours with hail and thunderstorms drifting slowly eastward as shown in plate 3, figure 2. Although a temperature difference of 5° to 10° Fahrenheit marked the division between cP and mT air, the major difference in surface flow during the daylight hours of the 27th was a wind shift from south to north following the squall-line passage. Toward evening an intense zone of surface convergence was centered in the vicinity of Hall County and presumably intensified the two large cells which produced the hail damage. The situation at the surface at 2200 is shown in plate 4, figure 1.

During the late afternoon and early part of the evening until 2000, large CB and towering cumulus were noted by Weather Bureau observers at Grand Island in the area from the northeast to the south of that station.

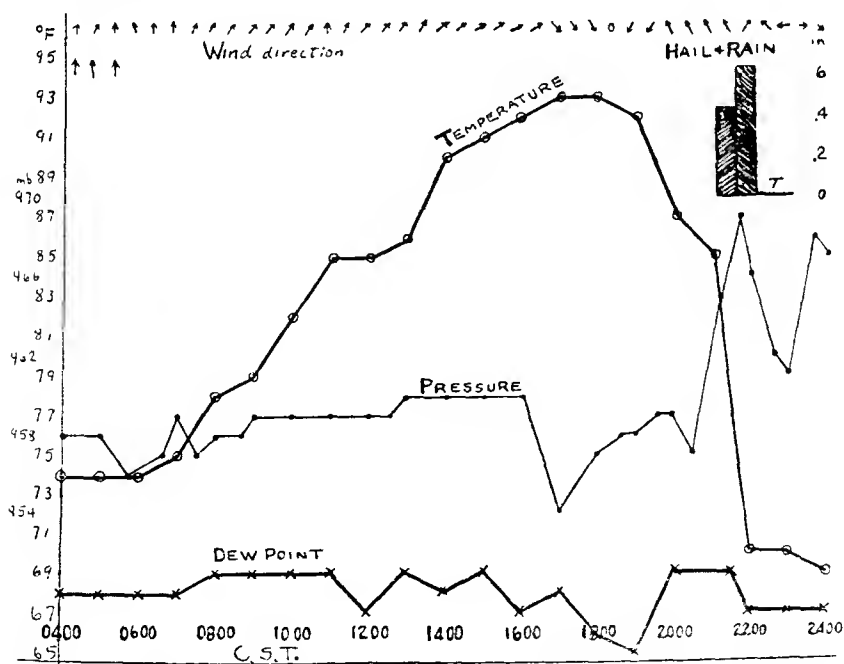


FIGURE 1.—Pressure, temperature, dewpoint, and precipitation at Grand Island, Nebr., June 27, 1959.

At 2000 the first evidence of lightning was noted in a large towering cumulonimbus actively developing in the WNW. By 2040 this storm was exhibiting continuous lightning. During the next half hour the leading edge had moved into the area, reached, and by 2120 had passed, the station. During this period a strong surface wind of 8 to 15 knots flowing from the SE. had been noted.

At the height of the storm, the pressure jump occurred. This is shown with related data in figure 1. The major change in pressure was preceded by a drop of 6 mb. recorded at 1658. The pressure returned to its previous level, fell a few millibars at 2030, then rose rapidly by 12 mb. which it reached at 2145. A pressure jump of 8 mb. occurred at the Grand Island airport at 2052. During this period wind gusts reached a peak of 83 knots from 205°, accompanied by hailstones up to 3 inches in diameter. Whether the grapefruit sizes mentioned by the newspapers and the Weather Bureau Climatological Report are an exaggeration is not known at present. Such stones have been photographed in the past from this general area. Stones of this size may have occurred, since holes were punched through the tail fins of a Flying Tiger cargo plane during the storm.

A total of 1.09 inches of rain was recorded from the storm with 0.65 measured in the 27 minutes between 2129 and 2156. During this period, the temperature dropped 15° F.—from 85° F. to 70° F. The maximum for the day was 94° F. reached about 1730. Throughout the day and during the storm, the dewpoint remained almost constant at 69° F.

The soundings obtained at the nearest radiosonde station, Omaha, Nebr., 115 miles east of Grand Island, indicated a suitable environment over the Great Plains for the development of very large hailstones. The SELS center in Kansas City forecast stones of 2 inches diameter, using their static analysis method for storms that might form in the Nebraska area in the vicinity of the frontal zone. According to information supplied by D. C. House [3], this forecast should have been weighted in favor of stones 3 inches or more in diameter, owing to a definite increase in low-level convergence just prior to the onset of the storm. During this same period, the core of a jetstream of 60 to 80 knots velocity swung across the area and probably had a strong influence on the dynamics of the convective clouds above the 300 mb. level.

2. PROPERTIES OF SOME OF THE HAILSTONES

Although some reports mentioned hailstones of grapefruit size, the largest ones available for research study were about 2½ inches diameter. These were shipped to the writer and studied [4] as part of a basic research program [5] in the atmospheric sciences conducted at

the Loomis School at Windsor, Conn. Subsequent detailed studies have been made of these stones in the writer's laboratory.

The stones show a variety of shapes and sizes although they have certain features in common. All of them show banded structure, indicating two or more changes in growth rate and/or environment. These changes appear to the casual observer as concentric bands of clear and cloudy ice, the so-called onionskin structure. Careful sectioning and etching reveal structures quite similar to those described and illustrated by List [6] and others. Typical stones are shown as cross sections in plate 5. It will be noted that the general structure of the stones is comprised of individual ice crystals of two sizes. The large crystals range in size from 1 to 4 millimeters, the smaller ones from 0.1 to 0.3 millimeter. This tenfold difference in size denotes either large variations in growth rate, moisture availability, or a combination of factors which caused the stones to grow in widely different environments.

3. COMMENTS ON POSSIBLE CAUSES OF OBSERVED FORMATIONS

In examining the crystalline structure of many large hailstones, it is noted that the smallest crystals are generally 10 to 30 times larger than ordinary cloud droplets. This can mean several things. The structures observed could be formed by the rapid freezing of mistlike droplets as they contact the hail embryo to form a porous graupel-like matrix. This porous, spongelike structure might then soak up liquid water as the stone sweeps it up at a rate faster than it can freeze upon contact.

A somewhat similar mechanism may be postulated involving cirrus-type ice crystals. In this case, however, water and ice crystals would coexist, the size of the ice crystals and their packing determining the final crystal sizes. Either of these processes could explain the uniform bands of small crystals found in most large hailstones.

The formation of the larger crystals may also be explained in at least two ways. They could represent zones of slow, wet growth. The crystals are often similar to those found in icicles or in hydromites, both of which are formed by relatively slow development. Some hailstones are certainly formed in this manner, since the elongated crystals observed as illustrated in plate 4, figure 2, could hardly be formed in any other way. Where the large crystals tend to have a fairly uniform size, they might represent the accretion of large, frozen raindrops agglomerating on the surface as a slushlike mass that is freezing at about the same rate as the water and ice mixture is being deposited.

One of the striking features of the crystalline pattern of large hailstones is the abrupt manner in which a change in crystal size occurs.

These cyclic zones may be produced by several different types of environments or processes. They could, for example, grow within and at the edge of the main core of a very large convective column and represent the fluctuating nature of the environment of such a complex dynamic structure. In a mature storm such as produces the larger hailstones, such columns must contain zones of subcooled cloud droplets, mist and rain, small ice crystals, frozen raindrops, and wet snowflakes.

A second situation, which might account for the variations observed, would involve wet growth within the core of a convective column or plume, followed by more rapid growth in a semiwet or dry condition as the hailstone is carried outward but remains within the less turbulent but colder zone of a horizontal ring vortex. The stone might be carried completely around the vortex and then into the central core to become again wet and denser as the porous structure becomes saturated with water. Considerable field evidence is available to indicate that hailstones are carried outward in ring vortices, since they are often thrown out of them and fall great distances through clear air.

Another condition, which could also account for the observed growth variations, would involve the successive development of convective turrets pushing up into the area where the stones are growing, each in turn having stronger vertical velocities and thus providing the increased energy necessary to keep the growing stone suspended within the cloud and at levels colder than 0°C .

It is likely that all three of these conditions, as well as other complex mechanisms, are underway simultaneously or going on in rapid succession within the region where the stones are growing. The considerable variation of growth patterns found in large hailstones from a single storm, as shown in plates 7 and 8, is the strongest evidence that this is probably the case. Larger stones do not fall from simple convective cumulus. They invariably occur under conditions that involve either an intense zone of large-scale convergence, as was the case with the Grand Island storm, or the development of the giant, isolated cumulonimbus that often occur east of the front range of the Rockies downwind of some of the large mountain peaks initiating them.

4. FACTORS THAT CAUSE SUCH STORMS IN THE WESTERN GREAT PLAINS

Easley [7] has studied and enumerated the various factors responsible for the intense hail incidence in the northeastern Colorado-Nebraska-Kansas area of the Great Plains. These include proximity of the mountains to the west, the ground elevation that is greater than 4,000 feet above sea level, the relatively low level of the freezing isotherm, the quasi-stationary trough to the lee of the mountains, the

moisture invasion channeled into the area from the Gulf of Mexico, and the role played by the mountains in removing the low-level moist air from the west but favoring the overrunning of the warm gulf air from the SSE. by cool, moist air aloft advected by a strong NNW. straight-line flow. When this occurs, there is often a relatively dry layer in between that favors the development of intense storms. She points out that cyclogenesis readily develops in the lee-side trough formed by the mountains when a slow-moving cold front moves across northeastern Colorado. The frontal waves emerging from this reaction move along the cold front, which slowly drifts to the northeast, and tend to develop violent squall lines at the interface. She points out that the June 27, 1959, storm considered here is a typical example of this type of synoptic pattern. This type of mesoscale system favors the formation of a few giant cells that may exceed vertical heights of 60,000 feet.

Further studies in this region will better establish the relationship of the lee waves of the jetstream produced by Sierra Blanca, Mount Evans, Long's Peak, and Laramie Peak, as well as their orographic effects. These particular mountains are often observed to form cloud streets and a triggering effect on convective activity, which is then reinforced in the lee trough mentioned by Easley. It is also possible that the normally low concentrations of nuclei for ice-crystal formation that characterize this area may play an important role in the hail formation so commonly observed in the area.

5. NEED FOR MORE CLOUD-SEEDING RESEARCH IN THIS REGION

Cloud-seeding efforts to modify or prevent hail have been centered in the past in the vicinity of Scotts Bluff, Nebr., and Sterling, Colo. This is probably a good location for affecting cumulonimbus, which develop locally. It is likely that a more effective technique for modifying large storms such as described in this paper requires the introduction of high concentrations of nuclei in the tongues of low-level moisture moving up from the Gulf of Mexico. The large, intense storms of this area develop so rapidly there is hardly time to spread adequately the silver iodide nuclei to prevent the development of large hailstones. Further efforts among research scientists, commercial cloud-seeding organizations, and farmers' groups need to be encouraged if further progress in understanding these severe storms is likely to be achieved.

Over the next few years many basic studies should be actively pursued in the Sterling-Scotts Bluff area of Colorado and Nebraska. A detailed mesoscale analysis should be made of particular storms, including photographic records from the air and ground, detailed studies of the hailstones produced, measurement of ice and condensa-

tion nuclei preceding and after storms, observations of their electrical nature, especially during the hail-forming period, and carefully planned aerial seeding carried out with high-output silver iodide generators.

The prevention of damaging hail will be one of the most useful achievements of experimental meteorology. Satisfactory progress will be made only when an adequate program is formulated and carried out.

6. ACKNOWLEDGMENTS

The author wishes to acknowledge with deep appreciation the cooperation received from many sources in assembling data for this study.

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The 1959-60 Eruption of Kilauea Volcano¹

By DONALD H. RICHTER and JERRY P. EATON

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[With 2 plates]

AT 8:08 p.m. on November 14, 1959, after nearly 5 years of quiescence, Kilauea, Hawaii's youngest volcano, renewed activity with an eruption at its summit. Thus began the spectacular surface display of the most complete sequence of eruptive activity yet recorded at Kilauea. Beginning with the inflation of the volcano by lava welling up from below and leading to a summit eruption, followed by accelerated inflation and breakdown of the rift zone to produce a flank eruption, and culminating in rapid deflation of the summit region with consequent collapse in the summit caldera,² the volcano performed as if on a vast geologic stage. As the geoscientists at the U.S. Geological Survey's Volcano Observatory closely followed the unrolling of this phenomenal volcanic sequence, they knew they were experiencing a "once in a lifetime" opportunity to add to our meager knowledge of the physics and chemistry of the earth's interior.

Kilauea, on the large island of Hawaii, is the southeasternmost of the volcanoes that form the mid-Pacific Hawaiian Archipelago (fig. 1). Built principally by the outpourings of many thousands of basaltic lava flows, Kilauea is a broad shield volcano rising 4,000 feet above sea level and some 20,000 feet above the ocean floor. Topographically Kilauea is only a slight bulge on the southeast slopes of its companion volcano, lofty Mauna Loa, standing 13,680 feet above sea level. Geologically, however, the two are separate volcanoes. Eruptions of Hawaiian volcanoes are generally confined to the summit areas or to the two or more principal rift zones that extend down the volcanoes' flanks from the summit and disappear under the ocean. On Kilauea, two rifts, a southwest and east rift, originate at the summit caldera, a downfaulted area 3 miles long and 2 miles wide.

¹ Reprinted by permission from *The New Scientist*, vol. 7, pp. 994-997, Apr. 21, 1960. Publication of article authorized by the Director, U.S. Geological Survey.

² A large, generally circular, volcanic depression whose diameter is much greater than the included volcanic vents.

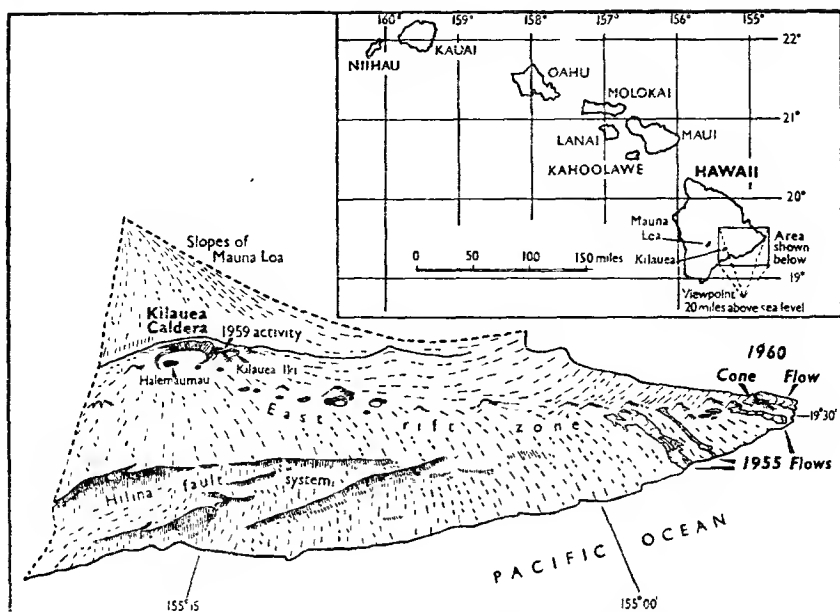


FIGURE 1.—Oblique perspective of a portion of the Island of Hawaii, showing the 1959-60 eruption sites on the summit and east rift zone of Kilauea Volcano. Vertical scale is exaggerated. Small-scale inset map shows principal islands in the Hawaiian Archipelago.

Within this large summit caldera of Kilauea is still another smaller depression, known as Halemaumau, the usual site of Kilauea summit eruptions.

The 1959-60 eruptive episode of Kilauea had its real beginning months before the first surface outbreak and miles beneath the Kilauea summit. Between October 1958 and February 1959, analysis of data from the U.S. Geological Survey's liquid-level tiltmeter bases,³ installed around the summit, indicated that the whole caldera region was swelling upward, suggesting that magma was welling up quietly from the depths and accumulating in a zone several miles beneath the caldera. Following several moderate earthquakes during February 1959, the swelling stopped; and from May until August the summit slowly subsided. In August a great swarm of earthquakes and tremors originating about 35 miles beneath the caldera was recorded by the U.S. Geological Survey's seismograph net on Hawaii. Magma moving into the deep volcanic plumbing system during this period made itself felt at the surface shortly, for rapid swelling of Kilauea resumed. In mid-September a very sensitive telerecording seismograph at the northeast edge of Halemaumau began recording a swarm of tiny quakes originating less than half a mile away. Al-

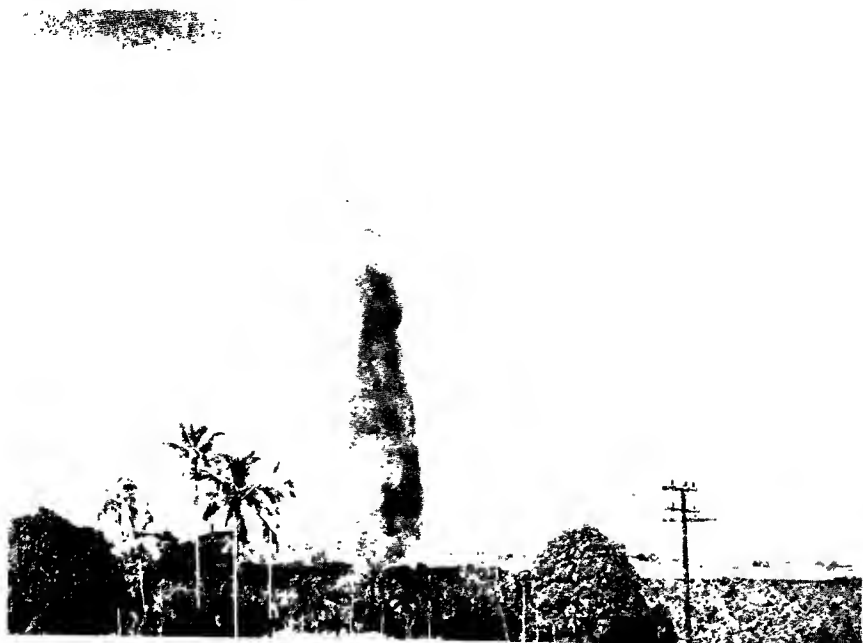
³ Piers for a portable water-tube leveling system which is capable of measuring very small differences in the inclination of the land surface.



1. View looking west across Kilauea Iki during the early morning of December 5, 1959 (fourth phase), showing fountain, cone, and incandescent glow through the cracks in the crust of the lava pond. Pond at this time was 395 feet deep.



2. Four-foot fault scarp on north side of Kapoho graben, formed during the period of strong earthquake activity on January 13, 1960, immediately preceding the flank eruption.



1. 1,400-foot fountain on January 19, 1960, during sixth day of flank eruption. Village of Kapoho is left of the fountain behind the palm trees.



2. Main road east of the village of Kapoho being crossed by slow-moving, blocky (aa) lava flow on January 27, 1960. Note buckling of asphalt pavement in the foreground and burning telephone pole.

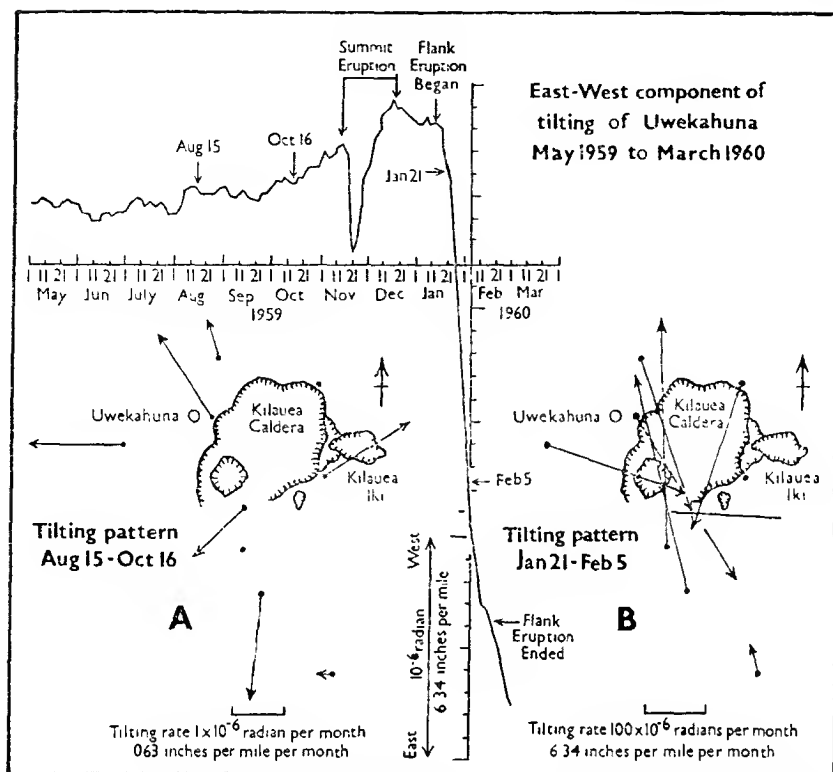


FIGURE 2.—East-west component of tilting at Uwekahuna from May 1959 to March 1960. Tilting toward the west corresponds to swelling of the summit of Kilauea and tilting toward the east to subsidence. Patterns of tilting around Kilauea Caldera are shown for slow swelling (inset A) and for rapid subsidence (inset B).

though these quakes were exceedingly small, their number was impressive; over 22,000 by November 14. Except for their smaller size they closely resembled those preceding the 1955 eruption of Kilauea from its east rift zone. Uncertain of the exact significance of these tiny shallow quakes, remeasurement of the tilt-base changes was initiated early in November. Dramatic changes had occurred: the caldera region was swelling at a rate at least three times faster than had been detected previously (inset A, fig. 2).

The eruption on the night of November 14 appeared at the surface with electrifying suddenness, not in Halemaumau as anticipated, but in Kilauea Iki, a pit crater about a mile long and half a mile wide, separated from the summit caldera by a low, narrow ridge. Starting in a single fissure halfway up the 600-foot south wall of the crater, lava fountains rapidly spread laterally in both directions. By 10 p.m. 10 short fissures, each with 1 or more active fountains, formed a discontinuous "curtain of fire" half a mile long. Gradually activity

ceased in the outermost vents and by 4 a.m. on November 15, only two fountains remained. One of these lasted through the early afternoon, when it too died; the other grew in size, eventually reaching the unprecedented height of 1,900 feet on December 17, during the 15th phase of the eruption.

With the eruption confined to a pit crater, sampling and observation were greatly facilitated; there was little danger to human life and only minor damage to the land and forest (pl. 1, fig. 1). Furthermore, rather precise calculations of the volume and rate of lava extrusion could be made, much the same as in a graduated cylinder. The first phase of the summit eruption lasted a half hour less than a week, forming a lava pond in Kilauea Iki 335 feet deep and containing 40 million cubic yards of fresh basaltic lava. After a brief 5-day respite activity resumed. Sixteen additional eruptive phases of much shorter duration occurred in the 3-week period that ended December 20, 1959, and contributed an additional 11 million cubic yards of lava to the pond, increasing its depth to a maximum of 414 feet.

Although the duration of the later phases decreased, the rate of lava output increased. In the first phase a maximum of 500,000 cubic yards per hour was measured; the 16th phase spewed out its lava at the phenomenal rate of 1,600,000 cubic yards per hour. From the end of the second phase when the level of the pond rose above the volcanic vent, liquid lava drained back into the vent each time the fountain stopped. In fact, almost all the lava erupted after the end of the sixth phase poured back down the vent. The rates for this withdrawal were also phenomenally high. Although less accurately determined than the extrusive rates, backflow rates exceeding 3 million cubic yards per hour, or almost four times the average rate of extrusion, were measured. Inasmuch as the lava of these later phases was still heavily charged with gas and had not decreased in temperature significantly, it appears that the lava draining back into the vent was not recycled but merely added to the enormous bulk of magma in the intricate system underneath the summit which fed the vent.

The temperature of the lava erupted at Kilauea Iki was consistently measured between 1,120° and 1,190° C. The percentage of silica in the lava varied between 46.3 and 49.5 during the early phases, but more or less stabilized at 46.8 after the fourth phase. Petrographically the lava is a tholeiitic picrite basalt, consisting of olivine phenocrysts set in a fine-grained groundmass of plagioclase feldspar, pyroxene, and glass. The high temperature, mineralogy, and chemistry correlate with the generally "primitive" nature of the lava, modified only by accumulation of olivine.

After the cessation of surface activity in Kilauea Iki on December 20, 1959, only small harmonic tremor, indicating minor lava movement

at depth, was recorded on the Survey's seismographs. Tilt measurements, however, showed extremely rapid tumescence of the summit area, strongly suggesting that magma was still welling up from the depths and that the eruption was not over. Supplementing the seismograph network with a sensitive portable seismograph late in December, Survey scientists followed the development of a swarm of small earthquakes along Kilauea's east rift zone, 24 miles from Kilauea Iki and not far from the site of the first outbreak of the 1955 flank eruption. It appeared that magma inflating the summit region was also exerting pressure on the plastic cores of the rift zones. As the rift zones yielded, earthquakes revealed where dikes began to open toward the surface. In early January the frequency and size of the earthquakes in the east rift zone increased, and the area from which they emanated moved on toward the sea. On January 13 strong earthquakes centered near the village of Kapoho 28 miles east of Kilauea's summit, and an old graben * 2 miles long and half a mile wide, which contained part of the village and most of the farmland that sustained it, began to subside. By nightfall displacements along the faults bounding the graben had grown to several feet (pl. 1, fig. 2), and Kapoho was evacuated.

At 7:30 that evening the flank eruption began along a line of en echelon fissures 0.7 mile long, a few hundred yards north of the village. Once more the eruption started as a dazzling incandescent curtain of fire that within 2 days shrank to a main eruptive zone, which continued fountaining throughout the flank eruption stage (pl. 2, fig. 1). Three hours after the initial outbreak, sea water gained access to the main vent area producing dense voluminous steam, salt, and fine ash clouds that roared 2,000 feet into the air. Within a few hours, however, fluid lava effectively sealed the conduits and only occasionally during the following 3 weeks was there appreciable steam emission.

The main fountain area, 2 miles from the seacoast at an elevation of approximately 90 feet, soon produced a steady stream of lava that slowly flowed down through the graben, reaching the sea on the night of January 15. At the end of the first week of the eruption the low graben area was essentially filled; and although lava continued to push slowly into the sea, the reduced gradient forced material to spread laterally over the adjacent old land surface (pl. 2, fig. 2). Slowly the lava flows inundated the village of Kapoho, the smaller community of Koae to the north, a U.S. Coast Guard station, and a number of beach residences along the coast. On February 6, when lava extrusion had essentially ceased, approximately 156 million cubic yards of lava had formed a pad of about 2,500 acres, including about 500 acres of

* An elongated block which has subsided between a pair of normal faults.

new land beyond the former coastline. Between February 6 and February 20 the main vent area continued to emit gas, spatter, and pumice, building a large cone to a height of 420 feet above sea level.

The first lavas extruded in the flank eruption were very similar chemically and mineralogically to the lavas erupted in 1955, and it is highly probable that they represent magma stored in a relatively near surface reservoir after the activity in 1955. Both lavas are poor in olivine but contain abundant phenocrysts of plagioclase feldspar and pyroxene. Their degree of differentiation is also shown by the relatively high silica content of about 50 percent. Near the end of January, after 2 weeks of steady eruption, the nature of the lava gradually changed. The temperature increased to 1,100° C., compared to 1,050° to 1,060° C. for the earlier material, the viscosity decreased, and olivine phenocrysts became abundant. Apparently the magma which was forcing its way through the rift zone from the summit was only then reaching the flank eruption area. During the last week of strong lava output in February, the temperature increased even more—maximum measured was 1,130° C.—and the lava was nearly identical to that of Kilauea Iki.

Shortly after the outbreak of the flank eruption tilt measurements revealed a very rapid settling of the summit area (inset B, fig. 2), and by the end of January a strong swarm of shallow earthquakes was being recorded at the summit stations. As more and more lava moved from the summit area through the rift zone toward the flank eruption, the settling became even more pronounced and the earthquakes more frequent. Strong, frequent earthquakes from the vicinity of 450-foot-deep Halemaumau, together with the issuance of steam from new areas around its floor, led Survey scientists to believe that the rapid withdrawal of lava from beneath the caldera might result in some form of surface collapse. By daybreak on February 7 the collapse had begun, and within a few hours the former flat floor of Halemaumau was a saucer-shaped depression 150 feet below its original level. Then just before noon and within a period of 10 minutes a small area, 1,000 feet in diameter in the center of the larger collapse feature, dropped an additional 200 feet, and a small volume of highly viscous lava oozed into the newly formed hole. Through the afternoon the subsidence gradually ceased and the oozing of lava abated. Two days later another smaller collapse occurred in the floor, but was not accompanied by the extrusion of lava. All the collapse appears to be directly attributable to the withdrawal of a portion of the still fluid core in the 300-foot lava lake which filled Halemaumau in 1952. Some lava, however, was forced outward into the innermost collapse pit by the lithostatic pressure being applied around the periphery of the main collapse area.

Although, at the time of this writing, earthquakes are still being recorded under Kilauea's summit and the summit is still deflating, the collapse in Halemaumau appears to be the culmination of this dramatic and enlightening volcanic episode. Never before has the sequence of summit eruption, flank eruption, and summit collapse of Kilauea Volcano been manifested so rapidly and completely.

Diamonds¹

By H. J. LOGIE ²

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I HAVE chosen in this inaugural lecture to talk about the diamond; it is the hardest known natural mineral; it cannot be scratched by anything but another diamond; it cannot be dissolved by any known liquid or melted by any conventional techniques. From the scientific point of view it is the prototype of crystals which show covalent bonding and from this viewpoint alone it is of great interest, since the whole crystal can be looked on as one giant molecule.

Much of the wealth of South Africa has come from gold and from diamonds, and yet it is remarkable how little research has been done in this country into the fundamental properties of either. In the case of diamonds, the Diamond Research Laboratories in Johannesburg are a notable exception and it was largely through financial help from them that a program of diamond research was instituted at this university. It is some of the results of these studies which will be presented in this lecture. However, though the ordered inner structure of the diamond is the chief concern of the scientist and of this lecture, even the scientist cannot be completely indifferent to the outward beauty of the gem nor can he fail to be intrigued by the part which diamonds have played in the history of this country, and by the stories which have grown up around some of them. I would not be doing full justice to the subject if these aspects were completely ignored.

With complete lack of scientific foundation, the diamond has been credited with many marvelous virtues; amongst others the power of averting insanity and of being an antidote to poison; and in the Middle Ages it was known as the *pietra della reconciliazione*—as the peacemaker between husband and wife. I understand that a belief in this property is not without its adherents today. The diamond,

¹ Inaugural lecture delivered May 21, 1958, at the University of the Witwatersrand. Reprinted by permission of the Witwatersrand University Press, Johannesburg, South Africa, publishers.

² Professor Logie died Nov. 8, 1958.

however, has not always played the part of the peacemaker. You may recall Becky Sharp's diamonds. The wicked Lord Steyn gave them to her and she kept them hidden from her husband Rawdon Crawley, and only wore them when she secretly entertained her wealthy benefactor. One night Rawdon came home unexpectedly and found Becky hung with trinkets and singing to Lord Steyn. He was so angered that he tore the diamonds from her and ground them beneath his heel and left home forever. Then there is the delightful scene of the servant creeping into the room afterwards, picking up the diamonds and running away with them, broken as they were.

Another story that springs to mind is the one which Dumas tells in his novel "The Queen's Necklace." This extraordinary affair took place at the French Court in the time of Louis XV and involved the King, Madame du Barry, the Prince Cardinal de Rohan, and Marie Antoinette. A magnificent diamond necklace was made by the court jeweler in the hope that it would be bought by Louis XV. His death in 1774 left the jeweler without a purchaser until an adventuress "Countess" Lamotte and her partner the notorious trickster, Cagliostro, managed to dupe the Cardinal into buying the necklace on behalf of the Queen. All was eventually discovered, but not before the necklace had been broken up and sold piecemeal and the scandal had aroused popular feeling against Marie Antoinette who was entirely blameless, and in fact, ignorant of it all. The populace of Paris, in that state of excitement and rage which terminated in the Reign of Terror, could not be convinced of this, and even at the last, the mob that surrounded the tumbril that bore the unfortunate queen to the guillotine, cast slurs upon her on account of this diamond necklace affair.

Almost as fantastic as stories which have been written about diamonds are the accounts of attempts which have been made to manufacture diamonds artificially. Until fairly recently there is no evidence to show that any of the claimants to success were any more than optimists or charlatans. But 3 or 4 years ago the General Electric Co. in America did manage to achieve the enormous temperatures and pressures which are needed to produce diamonds in the laboratory, and now have an output of $3\frac{1}{2}$ million carats per annum of industrial diamond grit. When it is remembered that the South African export market for this class of diamond is 11 million carats per annum, it will be appreciated that the scale of production of the artificial stones is by no means a negligible one. In some applications these artificial diamonds are superior to the natural ones, in other cases they are not.

Prior to this very remarkable achievement on the part of scientists at the General Electric Co., we relied upon geologists and prospectors and miners to meet the demand for these precious stones. Diamonds

are found in Nature as single crystals and seldom showing any sign of having been previously attached to any matrix. Absolutely colorless stones are not as common as cloudy or faintly colored specimens; the most common tints are gray, brown, yellow, and blue-white. Much more exotic colors are also sometimes found, and red, green, blue, and black stones are known. When the diamond has been cut and polished as a brilliant, it has 58 facets and in a tasteful setting is a thing of great beauty. Even people who do not long to possess diamonds are seldom indifferent to their attractions. And this despite the fact that diamonds and graphite are made of the same single element—carbon. They are in fact different in appearance and characteristics only because the carbon atoms have been packed together in a slightly different way. We shall return to this point later.

There is art in the production of a gem stone. Nearly all the finest jewels reach the lapidary as rough stones of typically octahedral shape. The first task is to saw the diamond into two parts. Along certain planes the sawing process is easy; along others it is difficult. Similarly when it comes to polishing the faces, which is done on a revolving wheel impregnated with diamond dust (a method which was hit upon shortly before Columbus discovered America), it is found that it can best be done in certain directions rather than in others. The diamond cutters speak of this as being due to the "grain" of the stone, and on any face there are "easy" and "hard" polishing directions which may differ in their abrasive hardness by a factor of 10,000. All this has been a matter of scientific study, and only recently and after centuries of tradition, has the lapidary's art been changed to a science.

Provided that the size of the diamond is convenient—and size, or rather weight, is measured in carats with 142 carats to the ounce—the cutter will divide the rough diamond into two parts by sawing along a plane parallel to the base of the two pyramids which form the octahedron. The larger portion is the more economical to work with. The corners are rounded off, then the bezel and the pavilion are polished to make 58 facets in all. About half the weight will be lost in the process, but the rather dull-looking stone has come to life as a result. The unusual brilliance of a diamond is due to its high refractive index (2.42) which makes the critical angle $24\frac{1}{2}^\circ$; the very high dispersion of the diamond gives it the "fire" or display of spectral colors.

For centuries diamonds have been cut and polished using methods similar to these and in the case of some of the great jewels which have been in existence for hundreds of years, one is amazed at the excellence of the work. Round these huge diamonds, which have usually been the property of kings, there have grown many legends partly of truth and partly of fiction. Perhaps the best known of

the great gems is the Regent or Pitt diamond, originally a rough stone of 410 carats which was cut down to 136 carats in polishing. It was bought by Pitt, the Governor of Fort St. George, in Madras, for £20,000. He sold it to the Regent of France for £135,000. It disappeared during the French Revolution, was returned, was used as security for loans from Holland, and finally Napoleon had it mounted on the hilt of his sword. It is now in the Louvre in Paris.

The Orloff of 195 carats, a rose-colored diamond, is also well known. It was stolen by a French soldier from a Brahmin idol and was bought by Prince Orloff for £90,000 and is now in the Russian Treasury.

The Shah of Persia (85 carats) is another great Eastern gem and is unique in having Arabic inscriptions on three of its faces. At one time it belonged to Shah Jehan who, it will be remembered, built the Taj Mahal. His son's name is inscribed on the face of the diamond and two of the other owners also had their names engraved on the diamond: a truly prodigious feat of the lapidary. Our knowledge of the history of many of these jewels is due to Tavernier, who was born in France at the start of the 17th century. He was a jewel merchant who traveled extensively in the East and who made careful observation of the great diamonds which were known at that time. One of the gems which he brought back to Europe on his return was the Blue Tavernier. This stone was sold to the King of France; it was later cut up and the Hope diamond forms a part of it. A great deal of ill fortune has attended the owners of the Hope diamond and a tradition of superstition has grown up around the stone. It is now owned by Mr. Harry Winston, an American who is not superstitious.³

Probably the greatest jewel which Tavernier saw on his travels was the Great Mogul (260 carats), which at that time was in the treasury of Aurangzeb, the last of the really strong Mogul emperors of India in 1665. By treachery this jewel came into the possession of Shah Jehan, whose son Aurangzeb overthrew his father and confined him to prison: he was captive at the time of Tavernier's visit and died soon after. With the death of Aurangzeb, the diamond disappeared and what happened to it is not known for certain. It was probably cut into two parts, one of which became the Koh-i-noor (meaning "the mountain of light") and under this name returned to India in the 19th century and was owned by Ranjit Singh, ruler of the Punjab. If the Koh-i-noor is indeed the Great Mogul, then 83 carats were lost in the 200 years of its disappearance. One of its owners in the interval had perhaps impoverished himself in time of

³ EDITOR'S NOTE.—In 1958 the Hope diamond was presented by Mr. Winston to the Smithsonian Institution, where it is displayed to the public in the Institution's Museum of Natural History.

war and had knocked some pieces off the giant stone and sold them. The two flat planes from which these pieces had been detached were easy to see when the Koh-i-noor was in the possession of Ranjit Singh. Even what was left of the Great Mogul was still worth more than a million pounds at that time.

In the war against the British, the Punjab was overrun and the Koh-i-noor fell into British hands. It was given for safekeeping to John Lawrence, later Governor-General of India, who kept it in a small tin box. For 6 weeks he forgot about it until it was needed as a gift for Queen Victoria. Then to his dismay the box could not be found. As a matter of fact it was still in the house. His Indian valet had found it while changing the contents of his master's pockets and, though he thought the diamond was a worthless piece of glass, he was too well trained to throw it away.

There was a big fuss made about the Koh-i-noor when it arrived at Buckingham Palace. Even a tyro could see that it needed recutting and the question immediately arose as to who should do the job. England was singularly poor in cutters at the time and apparently everybody participated in the repolishing, for we are told:

* * * in consequence of the keen interest evidenced by Her Most Gracious Majesty the Queen and the Prince Consort, in the manipulation of this wonderful gem, Messrs. Garrard, the Queen's jewelers, had a room specially fitted up where Her Majesty personally assisted in putting on the facets.

It is not surprising that the stone is still considered to be in bad shape.

The greatest of all diamonds comes from Cullinan. It was originally 3,025¾ carats (11⅓ pounds), was found in 1907 and was given to Edward VII. It has been cut into 9 large stones of 516 carats, 309 carats, and 7 others of less than 100 carats each and into many smaller ones. The two largest portions of the Cullinan diamond are still the biggest diamonds in existence.

The Cullinan is the largest diamond to come from South Africa, but a great deal of fascinating history is associated with even the smaller stones which have been found in this country. Nobody knows for certain whether the first diamond was found in South Africa in 1866 or in 1867. We are not sure either whether it was Schalk van Niekerk who first recognized the plaything of the Jacobs's children as a diamond, or whether it was Jack O'Reilly. An account of the event was given in 1932 by Erasmus Stephanus Jacobs. He said:

* * * our family lived on the farm De Kalk on the south side of the Orange River in the district of Hopetown. One day a water pipe leading out of the dam became choked up and my father sent me out on the veld to cut a long branch in order to clear the pipe. Having secured what I wanted, and feeling somewhat tired, I sat down in the shade of a tree, when I suddenly noticed in the glare of the strong sun a glittering pebble some yards away. I picked up the stone which lay a few hundred yards from the bank of the Orange River.

I put the pebble in my pocket and later gave it to my younger sister who put it with her playthings. Some months later my brother and I were playing a game called "Five Stones" and one of the stones was the diamond. Van Niekerk arrived during the game and greatly admired the stone and tried to scratch a windowpane with it. My mother noticed that van Niekerk had taken quite a fancy to this white stone and gave it to him.

Schalk van Niekerk, who lived in a house on the Jacobs's property, was a divisional councilor; a sort of welfare officer appointed by the farmers of the Hopetown district. It is exasperating not to know whether Van Niekerk was on the lookout for diamonds or not or if this one just happened to catch his eye. His attempt to scratch the windowpane leads one to think that he believed the stone was a diamond; on the other hand, he sold it to O'Reilly for only a few pounds.

Jack O'Reilly was a pedlar, a hunter, and a famous shot. Whether or not Van Niekerk knew he was selling a diamond is not clear; what is certain is that O'Reilly was convinced that he was buying one. He wrote his name on a windowpane, as seemed to be traditional, and sent the stone to Atherstone, a mineralogist living in Grahamstown. Atherstone seems to have consulted various people, including the Catholic Bishop, Richards, who wrote his name on a windowpane with the stone. Atherstone and Bishop Richards next tried a file which left the stone untouched, and they told O'Reilly that he really had a diamond. Eventually it was sold to the Governor of the Cape Colony, Sir Philip Wodehouse, for £500. Sir Philip had it shown at the Paris exhibition of 1867. It is remembered as a clear blue-white stone of $21\frac{1}{4}$ carats, but what happened to it after Sir Philip's death is not known.

O'Reilly's discovery was soon noised abroad and people all over South Africa began looking for diamonds. In time further discoveries were made, and by 1869 the diamond rush was on.

The diamond discovered by Jacobs was an alluvial stone. Water had carried it from its original source to its place of discovery. It probably had come a long way, because diamonds are formed only in the presence of great heat and great pressure: in fact, in the sort of conditions that occur in the crater or pipe of a volcano. A mass of molten rock released from the earth's core produces a number of minerals as it cools and these crystallize out in concentrated form. Carbon is one of these minerals, and under suitable conditions of temperature and pressure it may crystallize to form diamonds. That a diamond is nothing more than carbon may be proved by heating one in an atmosphere of pure oxygen. It will burn to carbon dioxide without any residue. Under slightly different conditions these self-same carbon atoms may crystallize into graphite instead of into diamond. The two forms, diamond and graphite, are said to be poly-

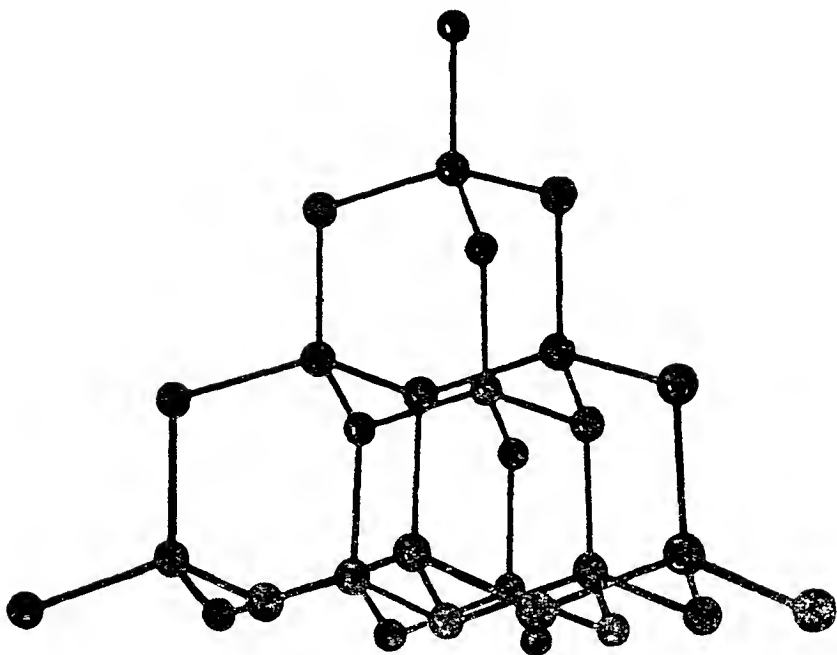


FIGURE 1.

morphic, and a comparison of the properties of the two helps us to understand what is important in determining those properties.

Diamond has a density of 3.51 g./cc. against 2.25 g./cc. for graphite, so that the carbon atoms are not packed together as closely in graphite as they are in diamond. The X-ray analysis has confirmed a structural difference between the two. Diamond crystallizes in a cubic system with each atom symmetrically surrounded by four close neighbors, all at the same distance and arranged at the corners of a regular tetrahedron. (See fig. 1.) Diamond may also be thought of as two interpenetrating face-centered cubic lattices, one of which is displaced relative to the other by a quarter of the distance along the main diagonal (fig. 2). The angle which the bonds between the atoms make with each other is $109^{\circ}28'$. Both the strength of the bonds and their direction influence the properties of the material. The melting point of substances is largely determined by the directed nature of the forces between atoms, and where they are as strictly directed as in the case of the diamond, there the melting point of the substance is very high. In ionic crystals, where the bonds are not strictly directed and the forces merely require that there shall be a great number of oppositely charged ions close to each other, the melting point is low. In metals, we find frequently a tendency for each atom in the crystal to gather round it the greatest possible number of nearest neighbors (12)

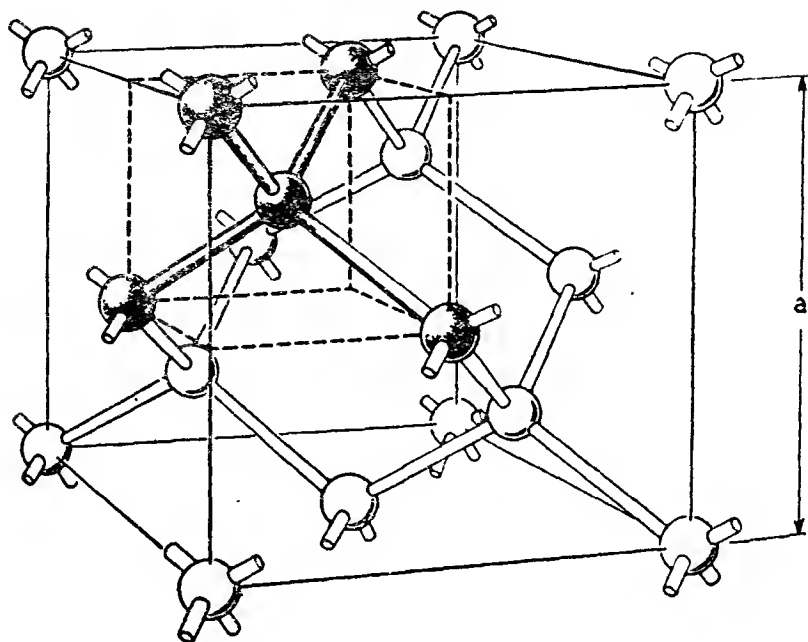


FIGURE 2.

resulting in close-packed structures with not too rigidly fixed angles and comparatively low melting points, because in the liquid state the number of neighboring atoms has not greatly changed and they do not have to be in particular directions with respect to each other.

Graphite crystallizes in the hexagonal system; the atoms are arranged in layers; within each layer the pattern is not greatly different from the arrangement in diamond, but the layers are separated by comparatively large distances (fig. 3). It is this change in the atomic arrangement that makes graphite a good lubricant, for the layers can slip over one another under the action of weak binding forces. It is also this change in spacing which accounts for the fact that graphite is a conductor of electricity while diamond is an insulator; it accounts also for the opaque black color, the lower density and the different thermal conductivities of the two substances. In the diamond the spacing between layers is 1.54 Å. In the case of graphite it is 3.35 Å. This small difference is responsible for the distinctive physical properties of the two substances. It is characteristic of the diamond, as we shall see, that small effects produce results out of all proportion.

While comparing graphite and diamond, there are two paradoxes worthy of mention. First, one would imagine that the hard diamond is the more stable structure. In fact, it is the other way about

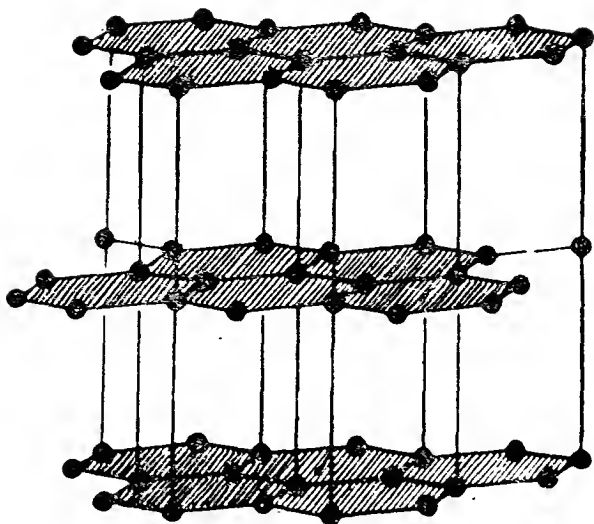


FIGURE 3.

at room temperature. The diamond is the preferred structure in a region where the pressure is above 20,000 atmospheres, or about 300,000 p.s.i., while graphite is the preferred structure at normal conditions of pressure and temperature. It is the enormous pressures in the cooling magma of a volcano which is needed for the production of a diamond. In more precise terms, one would say that the thermodynamic potential of graphite is lower than that of diamond, and it follows that if any transformation is to take place at all, at room temperature it will be from diamond to graphite and not vice versa. But thermodynamic stability is not the same as mechanical stability, and although diamond has a thermodynamic permission to transform itself into graphite, it has no mandate to do so. My wife has worn her engagement ring these many years with no solicitude on that score.

The second strange fact is, that although diamond has a density of 3.5 g./cc. and is the hardest known substance, its atoms are not packed in the closest possible geometrical arrangement. It would be much denser if each atom were surrounded, not by 4, but by 12 other equidistant atoms as is the case for many metallic substances. In fact, by packing spheres together in the diamond structure, only 46 percent of the available space is used. We would describe the diamond lattice as having a very open structure.

It was this fact that led us to attempt a few months ago to diffuse impurity atoms into the diamond. The idea was that by heating the diamond to several hundred degrees centigrade in a vacuum and while it was embedded in a material like boron which has a small

atomic radius, some of the boron atoms might diffuse into the holes in the diamond.

I doubt whether we were successful in these attempts, but we did find that using carbon instead of boron led to an interesting effect. After being heated in this way it was found that when a voltage was applied to the crystal, it glowed with a bright green color. This is a quite new electroluminescent effect which diamonds do not normally show. The precise mechanism involved in the production of light is not clear, and with all our other interests we have had to put this aside for a future, less busy time. However, the effect itself is very beautiful.

Several properties of the diamond and indeed of all solids are mainly controlled by the form of the lattice and its modes of vibration. The specific heat is one of the best known in this respect. There are other properties, such as electrical conductivity, which are thought of as being mainly controlled by the electrons in the crystal. A division such as this is more apparent than real, for of course there is always interaction between the lattice and the electrons, and the one affects the other. With this reservation, let us consider two properties. The first is thermal conductivity.

Those who have handled large diamonds will have been struck by how cold a handful of them feel. Wool and felt are warm to the touch, metals are cold and diamonds are colder still. These feelings of warmth and of cold are because of the thermal conductivity of the material. A metal such as copper is a very good conductor of heat, but the thermal conductivity of diamond is four times as good at room temperature. Copper has a thermal conductivity of 4.1 watts/cm. deg. K. and diamond 16 watts/cm. deg. K. If different parts of a solid are at different temperatures, then heat may be transferred from the hot to the cold parts by two processes. The transfer may be due to free electrons moving through the lattice, rather like convection currents in gases; or it may be due to vibrations or waves passing down the lattice, rather like heat transfer by radiation in a gas. The waves traveling through the lattice are referred to as phonons, and the whole structure behaves, as Kathleen Lonsdale has remarked, like granadilla pips wobbling in a soft jelly. In the case of copper there are large numbers of electrons freely available in the crystal to participate in the conduction of heat, but for the diamond, none of the electrons are free and we are left with the lattice vibrations as the mode of heat transfer.

In a gas the thermal conductivity is given by the expression $s = CuL/3$, where C is the heat capacity of unit volume, u is the average particle velocity and L is the mean free path of a particle between collisions. The idea of a mean free path for particles has been

carried over to the solid where it is applied to the phonons. The magnitude of L is determined by the scattering of phonons at the boundary of the crystal or by interaction with other phonons or by scattering at imperfections in the lattice. If the forces between atoms were purely harmonic, there would be no mechanism for collision between the phonons, and the mean free path in a perfect crystal would be limited solely by the size of the crystal. Because the thermal conductivity is so high we conclude that there are few imperfections in the crystal and further that the lattice vibrations are predominantly harmonic. This has other consequences.

By the statement that the oscillations are purely harmonic, we mean two things:

- (1) That the forces are proportional to the displacement of the nuclei; and
- (2) That all displacements of electric charges are proportional to the displacement of the nuclei.

Anharmonicity, that is lack of harmonicity, may accordingly be due to two things. First, the proportionality between nuclear displacements and restoring forces may not be satisfied. In this case we talk about mechanical anharmonicity. Or deviations may exist from the proportionality between nuclear displacements and the accompanying changes in the dipole moment. In this case there exists an electrical anharmonicity. The diamond shows neither of these effects and this has important consequences in the optical behavior of the crystal.

Infrared absorption is another property of a solid which depends on the vibration of the lattice. When light passes through a crystal it may lose energy by setting the atoms in motion, and strong absorption of the light occurs when its frequency is the same as the natural frequency of the lattice. Besides this requirement, absorption will occur only if the oscillations are not completely symmetrical in a given unit cell of the lattice. If the center of gravity of the cell does not change during an oscillation, then the opposite displacements of the atoms in the cell give rise to opposite values of radiated electric and magnetic fields, and the sum total of the field intensity in the radiation is zero. In a recent paper by Burstein, Picus, and Sclar,⁴ they point out that the diamond structure, consisting as it does of two identical interpenetrating face-centered cubic lattices, one of which is displaced relative to the other, will be infrared inactive because of the symmetrical considerations.

The history of the experiments and theory on the infrared absorption by diamonds is not without its lighter moments. In 1907, Einstein was the first to make a fairly reliable estimate of the vibration

⁴ "Optical and photo-conductive properties of Si and Ge." Photoconductivity Conference. New York, John Wiley, 1954.

spectrum of the diamond lattice. He predicted an absorption band at 8μ and although the basis of his calculation was not correct, nevertheless an absorption band at 8μ was found by some observers. Others failed to find the band. This disagreement in observation proved to be a consequence of the fact that diamonds are of two types: one of these does indeed have an absorption band at this wavelength, while the other does not. The origin of the absorption is far from settled, but it is almost certainly due to causes other than lattice vibrations.

What has been said so far is intended to give a picture of the behavior and arrangement of the carbon atoms in the diamond. To understand why they are arranged in this way and to explain many of the electrical properties of the diamond, it is necessary to look a little more closely at the carbon atom itself and inquire into its electronic structure.

The element carbon has an atomic number 6. This means that it has six units of positive charge on the nucleus and has six electrons moving in various orbits around the nucleus. It lies in the fourth column of the elements in the periodic table and has similar characteristics to silicon, germanium, tin, and lead, all of which belong to the same group. This seemingly diverse group of elements, which comprise two metals (tin and lead), two semiconductors (germanium and silicon), and diamond or graphite have one important attribute in common. They all have the same distribution of electrons in the outermost shells of the atom. In the case of carbon there are two electrons in the inner *K*-shell which take no part in any interactions with other atoms. Farther away from the nucleus, the four remaining electrons are fairly loosely held in the outermost *L*-shell. This outer shell is permitted by quantum conditions to accommodate eight electrons in all, so that the atom behaves as an element with four valence electrons and at the same time requires four more to complete the octet which fills the *L*-shell. It is well known that atoms which have incomplete outer shells combine readily with other elements which have electrons that can be detached and fill the vacancies. The chemical combination of carbon with four hydrogen atoms, each of which release an electron, or of carbon and two atoms of oxygen, each of which releases two electrons to fill the outer shell, are very well known. All the elements of group 4 behave chemically in much the same way.

Before we examine what happens to the electrons when we bring a number of carbon atoms together to form a crystal, it is necessary to consider the energy of the electrons in the free atom. The energy of an electron will depend in which orbit or shell it moves. If the electron spends most of its time near the nucleus, then its energy is lower than if it is in the outer orbit. The distribution of electrons and their

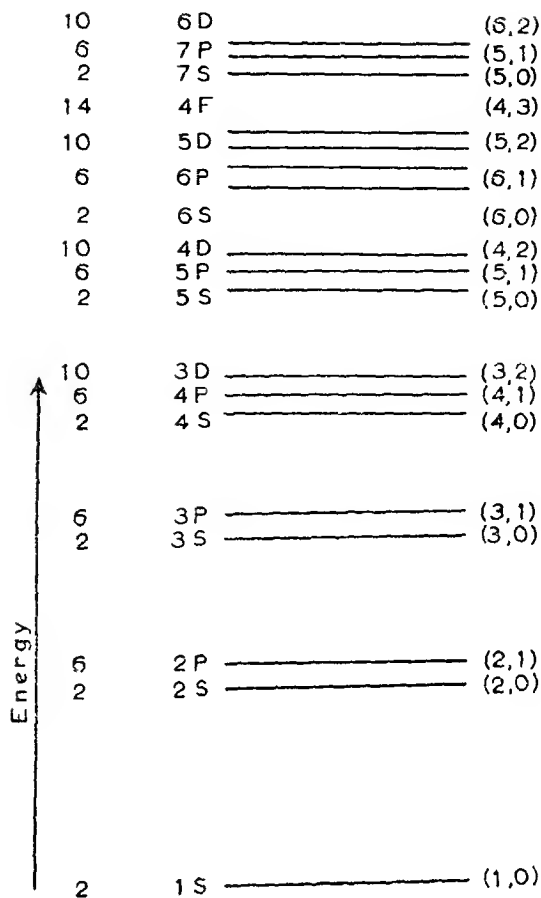


FIGURE 4.

respective energies are shown in figure 4. The orbit closest to the nucleus can have two electrons in it; then there is a fairly large energy gap and we come to a pair of orbits which together are known as the *L*-shell and which can accommodate eight electrons. Again there is a fairly wide energy gap before we come to the next group of possible orbits and so on. The two important points to appreciate at this stage are, first, that only certain energy levels are possible and between these levels there are energy values which are "forbidden," and second, that the closer an electron is to the nucleus, the lower is its energy.

As the carbon atoms are brought together to form a crystal, one can imagine the competition for the possession of electrons to fill the shells. An elegant compromise is reached. Each carbon atom takes four neighbors and shares an electron with each of them. A contribution of one electron from each atom will be found along the line joining two of them together. Every atom is now surrounded by

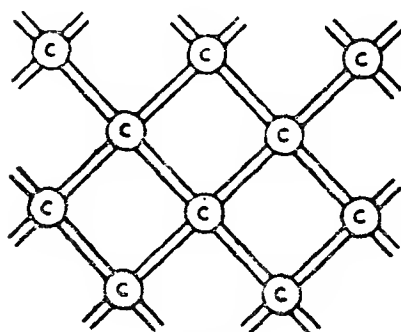
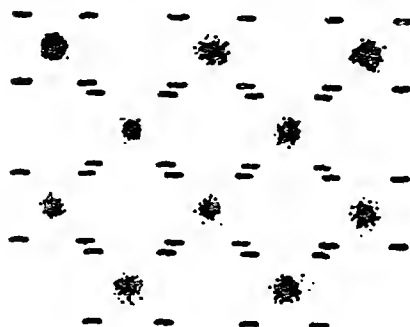


FIGURE 5.

eight electrons and in this way the outer shells are filled, as is shown diagrammatically in figure 5. Bonding such as this, where a valence electron from one atom is shared with the adjacent atom, is called covalent bonding. It is important to notice that all the valence electrons are held in the bonds and none are free to move. This kind of tetragonal structure is common to diamond, germanium, silicon, and certain forms of tin.

We consider next why the diamond has such great cohesive strength and why silicon and germanium are much softer although their crystal structures are the same. A comparison of the physical properties of these three substances is shown in table 1.

TABLE 1

	Melting point ($^{\circ}$ C.)	Dielectric constant	Energy gap (eV)	C_{11}	C_{12}	C_{44} (10^{12} dynes/cm.)
C.....	3, 550	5. 7	5. 6	9. 2	3. 9	4. 3
Si.....	1, 420	12	1. 21	. 67	. 65	. 80
Ge.....	936	16	. 79	1. 30	. 49	. 67

Some idea as to why there should be these differences in bonding energy can be gained by imagining the crystal to be assembled from a group of atoms which are initially far apart. We imagine the atoms to be brought closer and closer together until they are at the characteristic lattice spacing. Binding energy, which is so large in the case of the diamond, comes about because the electrons lower their energy as the atoms get closer. It was shown earlier that the energy of the electrons was less if they were closer to the nucleus, and this is precisely what happens when the atoms are brought together to form a solid. The valence electrons in the crystal are never very far from some atomic nucleus and their potential energy is thus much reduced. They are making better use of the positively charged cores by staying closer to them.

While the potential energy has been lowered, what has happened to the kinetic energy? All the valence electrons cannot have zero kinetic energy without violating the exclusion principle. This principle states simply that no two electrons may occupy one and the same quantum state. If it were not for a law of this nature, all the electrons would drop to the lowest energy level and the structure of the periodic table, the diversity of the elements, and this audience would not exist. In order to dispose of all the valence electrons in the crystal and yet have at most one electron per quantum state, a large range of momenta and therefore of kinetic energies must be found among the electrons. The band of energy states required to accommodate the electrons and the number of states which are occupied can be calculated using Fermi-Dirac statistics. The average kinetic energy per electron then turns out to be somewhat larger in the solid than in the gas. However, there still remains a net loss of energy for the atom as a whole. The binding forces arise then because the gain of kinetic energy does not completely offset the loss of potential energy. The net change is greater if the difference in the size of the atom and of the ion core is large. This explains the difference in the cohesive energy of the group IV elements and the fact that the binding energies are lowered as the atomic number is increased.

It has been remarked that the bonding in diamond is covalent. In the simplest terms, this means that a valence electron from one atom is shared with the adjacent atom and none of them is free to move through the crystal. The situation is usually represented by an energy band diagram like figure 6. Each band represents a group of closely spaced energy states in which the electrons may be. These energy bands have their counterpart in the discrete energy levels of the free atom. Just as the quantum conditions allow only certain widely separated energy levels in the atom, so also there are energy bands in the crystal which are separated from one another by "for-

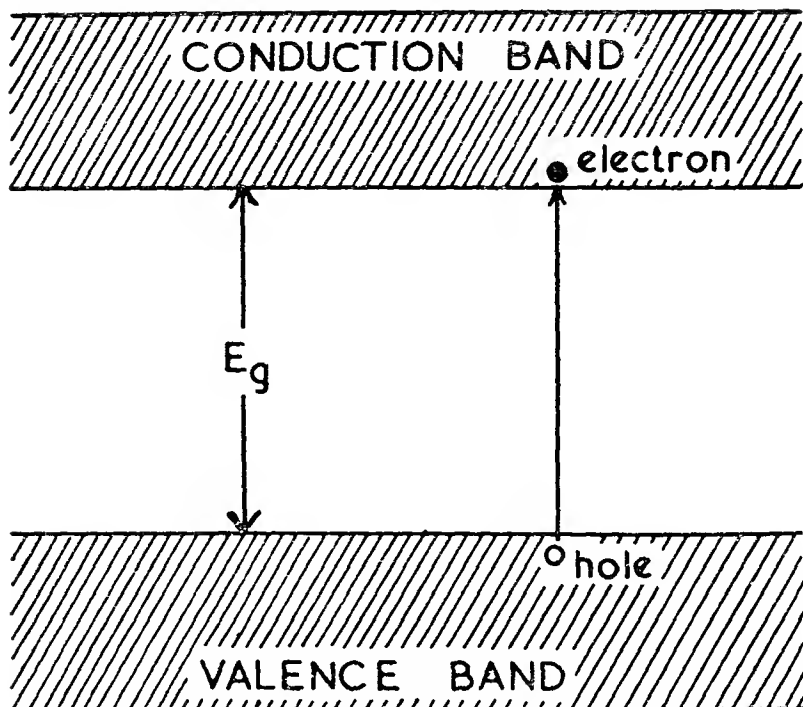


FIGURE 6.

bidden" energy gaps. As the atoms are brought together to form the crystal, the discrete energy levels in the atom spread out into energy bands, and the electrons are distributed among the possible energy levels in accordance with the exclusion principle and according to the statistical distribution of Fermi. The uppermost band is called the conduction band, while the next lower is called the valence band. For the energy of an electron to be changed, there must be an unoccupied level into which it may go. In the case of the diamond, the conduction band is empty and all the electrons are in the valence band and occupy all the possible states in that band. There are no unoccupied states in the lower band and consequently there is no possibility of small changes of energy being imparted to an electron. The closest unoccupied state is at the bottom to the conduction band and an energy of at least E_g must be imparted to the electron to effect this transition. The situation in this respect may be likened to a theater with a gallery. The seats represent the possible energy states and these are at two levels. The audience represents the electrons. If a seat has been reserved in the stalls, then quite a lot of energy is needed to obtain a transfer to the circle. In the case of the diamond, all the stall seats are full and all the circle seats are empty.

In addition, the height of the circle above the ground floor is large in comparison with most other materials which we normally encounter. Interpreted in another way, it means that all the electrons are firmly held in the covalent bonds and considerable energy is required to release them. This aspect of the diamond structure has been dwelt on at some length, but it is fundamental to an understanding of many processes in diamonds.

While the general picture which has been given here of the band structure of solids is generally followed by all materials, the details for various substances differ, and in particular the energy separation of the two bands is different and this profoundly affects the properties of the substance. In what follows we shall be mainly concerned with the passage of electrical currents and it is important to look into this aspect further.

The conduction of electricity in most of the processes which are encountered daily is due to the motion of electrons. Not all materials have the ability to conduct electricity, and solids have been divided into three categories. When there are electrons free to move about in the crystal, we have a conductor. Metals fall into this category. When there is no freedom of movement for the electrons, then the substance is called an insulator. There is an intermediate group of materials known as semiconductors, which become conductors only under certain conditions of temperature and purity. In the case of diamonds, one anticipates that they will behave as an insulator because all the available electrons are closely bound to the atoms and none can move about under the influence of an applied electric field. In order that a current should flow, some of the electrons must be made to move from their association with a given pair of atoms and be permitted to wander through the crystal. The question at once arises, How firmly are these electrons held? The answer is to be found in the band energy diagram of figure 6, which shows a forbidden energy gap of about 6 eV. If we think of the theater analogy again, the situation is that all the stall seats are full and for a person to move from one position to another (which would correspond to a flow of current) is not possible. The only way that freedom of movement can be achieved is by transferring one or more people to the gallery. These people in the almost empty gallery can now move about freely and at the same time the vacancies which now exist in the stalls enable an exchange of seats to take place there also. If one seat is vacant, for example, then as a general exchange of seats takes place, the appearance would be that of a vacant seat moving about from one position to another in the auditorium. Both these processes have their counterpart in what happens in crystals of the diamond type. Events in the gallery where an electron is thought to be moving in the conduction band are spoken

of as conduction by electrons. The apparent motion of the seat left vacant in the stalls corresponds to conduction by "positive holes."

It was pointed out earlier that carbon, silicon, germanium, tin, and lead all belong in the same column of the periodic table. The first three have identical crystal structures, but behave very differently electrically. Diamond is the insulator. It has an energy gap of about 6 eV. Silicon has a gap of 1.1 eV, in germanium the gap is 0.72 eV, in gray tin 0.1 eV, and in white tin and lead the energy bands overlap so that there is no forbidden energy region and they are good conductors.

The different conducting properties of graphite and diamond are now capable of interpretation. The largest atomic separation for graphite between nearest neighbors is that between the platelike layers which are shown in figure 3. This separation is 1.54 Å for diamond, and for graphite the separation is 3.35 Å. The average spacing in graphite is larger and corresponds to a region in which the energy bands overlap and the graphite behaves like a metal. Thinking in terms of the electron bonding, it is observed that in graphite the four valence electrons are shared by three nearest neighbors in one of the sheets of atoms. On the average, each atom can thus contribute part of an electron which is free to wander through the crystal and participate in electrical conduction.

As will be shown presently, though most diamonds are insulators, others are conductors and, by suitable treatment, all of them can be made conductors. To explain this, we inquire now into some of the possible ways in which electrons can be moved from the lower filled band into the upper empty one so that conduction becomes possible.

First there is the possibility that by heating the material an electron may be given sufficient energy to jump the gap. On substituting values for k , Boltzmann's constant, in the relation $E = kT$, it is found that to impart 1 electron volt would require temperatures of 10,000° centigrade. This method is clearly not applicable in the case of pure diamonds, but it does play an important part in semiconductors where the gap between the energy bands is much less than is the case for diamonds.

The second possibility is that light waves or photons could impart the required energy. When this happens, it is spoken of as photoconductivity. Using the Einstein relation $E = hc/\lambda$, the photon energy of visible light is found to lie between 1.6 eV at the red end of the spectrum and 3.2 eV in the blue. For the energy gap of diamond, light of wavelength 2,200 Å or less is required. This wavelength is in the ultraviolet region. The electron ejected by this means is now in the conduction band. If an electric field is applied to the crystal, the electron drifts in the direction of the applied field and carries a current. The vacant space from which the electron came constitutes

a localized positive hole which can move by reciprocal motion of thermally activated electrons in the valence band, and also contributes to the current. If the source of illumination is removed, the photoconductivity dies away by the recombination of electrons and holes. A certain amount of energy must be given up when this recombination occurs and may take several forms. One possible form is an increase in the temperature of the diamond. Another possibility is that when the electron and hole recombine, they may do so with the emission of visible light. This is spoken of as luminescence, but in pure diamonds this process will not occur.

If the light falling on the diamond has a wavelength in the ultraviolet, the electrons will acquire energy from the beam of light. We say that the light has been absorbed and that the diamond has an absorption band in the neighborhood of 2,200 Å. No absorption will occur for wavelengths longer than this, and no absorption in the visible part of the spectrum is anticipated. This means that if we start with white light, it should remain white after passing through the diamond. We are thus led to expect that all diamonds should be pure white, with no absorption bands to produce color in the visible part of the spectrum.

A third method of producing conductivity is by bombarding the crystal with small but energetic particles like electrons or alpha particles. When these impinge on the crystal, they collide with the electrons already present and remove them from their covalent bonds. As before, conduction by electrons and holes becomes possible. If the source of the energetic particles is a radioactive material, then each alpha, beta, or gamma ray of sufficient energy may release several hundred electrons into the conduction band, and the effect is a short-pulse of current for each incident particle.

The following properties of the diamond are expected on the basis of the above reasoning: it should be an insulator; it should be pure white; and it should show no luminescence and no photoconductivity for wavelengths greater than 2,200 Å. The actual behavior is in striking contrast to these predictions. We know that diamonds often are colored, that some of them do show luminescence, that they are sometimes conductors, and that they do have photoconductive properties when illuminated by white light. In short, if there is one fact which is very soon apparent to anyone investigating the properties of the diamond, it is that each stone seems to have a quality of its own. Some attempt has been made to group certain types of diamonds together according to their properties. This scheme is helpful, but there is no sharp boundary between one group and another. The first classification divides diamonds into type 1 and type 2, according to whether

the ultraviolet absorption becomes pronounced at wavelengths near 3,000 Å or near the theoretically expected 2,200 Å, respectively. All types show some infrared absorption and both show luminescence, though it is more marked in type 1 than in type 2. Often neither type is a perfect insulator, though their respective resistivities may be as high as 10^{14} ohm cm. Then there are type 2 diamonds which are colored and some which are good conductors. These latter were classified by Dr. Custers as type 2*b*, so that type 2*a* is reserved for diamonds with ultraviolet absorption at 2,200 Å which are insulators.

The divergence between the predicted properties and those which are actually realized is so marked that obviously there are other factors which have not yet been taken into account. Where the theory has been at fault is in leaving the energy gap between the valence band and the conduction band completely free of energy levels. As soon as it is accepted that some electrons may require less than 6 eV to reach the conduction band, then all the difficulties are removed. How can such a situation arise? It is now fairly clear that traces of impurities or defects in the lattice will produce just this effect. Imperfections of this kind, in concentrations as low as 1 part in 10 million, will explain all the anomalies.

Instead of dealing with each of the phenomena in turn, let us follow the investigations which have been made in our laboratories into the conductivity induced by alpha or beta particle bombardment of the crystal. As we consider the effects, I believe that a general understanding of most of the other phenomena will emerge.

It has long been known that certain crystals when bombarded by energetic particles are made temporarily conducting. The pioneer work in this field was done by Van Heerden and, from what has been said earlier, the effect of bombarding the diamond is to raise electrons from the valence band to the conduction band. If an electric field is applied to the diamond, it will sweep these electrons and holes toward the electrodes so that each incoming particle results in a pulse of current.

We see that the diamond behaves very much like a Geiger counter. In fact it has several advantages over a conventional Geiger tube. Its density is high so that the stopping power of the diamond is 3,000 times that of a gas. In other words, a 1 MeV beta particle which would travel through a meter of air will expend all its energy in 1 mm. of diamond. One cubic mm. of diamond is then as effective as several cubic centimeters of Geiger tube and is well suited to application where a small probe is necessary. The medical field is an example which immediately comes to mind. Diamond has an extremely fast resolving time and can distinguish particles arriving at intervals of 10^{-8} sec. It is thus capable of counting at the rate of

100 million particles per second. The energy to form an electron hole is about 6 eV, compared to 30 eV to produce ionization in air. It can count alpha, beta, and gamma particles of high energy as efficiently as a large Geiger counter.

All this is on the credit side. There are also drawbacks, perhaps the most serious, and certainly at first sight the most surprising of which, is that only a very small percentage of diamonds make good counters. Even among those that do count, there is a wide divergence in performance. Considerable attention has been paid by Champion, Dyer, Ditchburn, Willardson, and others to the correlation between the counting ability and other physical properties. Those diamonds whose absorption band is less than 2,500 Å are the most likely to have counting properties. Not all of them do, and of course there are some diamonds of type 1 which are counters also. The diamonds we have been using in this lecture are, in fact, type 1. Champion believes that counting diamonds are those which are composed of layers of highly perfect crystalline material separated by much thinner barriers of imperfect material. Again, diamonds which fluoresce are not likely to be good counters, though it does not follow that nonfluorescing diamonds are sure to count. There is fewer than one diamond in a thousand which can be classified as a good counter.

The second defect of the diamond counter is due to what has been termed "polarization." Many diamonds, even though they are good counters when they are first bombarded, lose their efficiency if the bombardment is continued. By giving the diamond a rest or by heating it or, sometimes, by irradiating it with ultraviolet light or gamma or beta radiation, it will recover its initial ability.

It is now time to turn to the modifications which result from defects or impurities in the diamond. The effect of these can easily be shown experimentally. One way of producing a defect in a diamond is to bombard it with neutrons. These neutrons are much heavier than electrons, and when they collide with a carbon atom in the lattice they knock it out of position. This kind of defect is called a vacancy. The electron bonds at this point in the crystal have been altered by the vacancy and the ease with which electrons at that point can be liberated and transferred to the conduction band has been changed; i.e., an energy level intermediate between the valence and conducting bands has been created. Diamonds which have been treated in this way show very marked changes in their properties. White diamonds become green and counting diamonds lose this ability.

There are three kinds of imperfections which may occur in crystals and are of interest to us. These are:

1. Vacancies such as those which have just been described.

2. Interstitials, when a carbon atom is displaced to some location between the atoms of an already complete lattice. The diamond lattice offers a relatively large amount of space for these interstitials.
3. Impurities, when a foreign atom replaces the normal carbon atom at one of the lattice sites.

If these defects form a small percentage of the possible lattice sites, then the energy diagram is represented as in figure 7. An energy level like the one at F' in the diagram might be due to an impurity atom, such as arsenic which has five valence electrons instead of four. Four of these electrons will be found in the covalent bonds between neighboring atoms, while the fifth will be rather loosely bound to the nucleus. A small increment of energy will remove this electron, and since there are no bonds which it can enter, it will constitute a mobile negative charge. The band picture places the impurity level F' fairly close to the conduction band. A small amount of additional energy is sufficient to raise it to the conduction band, when it will be free to move through the crystal. It leaves behind it a positively charged center which, in due time, may capture another electron and return to its original condition. An impurity of this kind, which may lose an electron and thus become a positive "trapped" hole, is called a donor impurity.

There are also acceptor impurities which have impurity levels near the valence band. Such impurities may be boron, for example, which has only three valence electrons and readily captures a fourth to complete the covalent bonds. It requires only a small amount of energy to raise an electron from the valence band into an acceptor level. The empty level left behind in the valence band is a mobile hole and the electron has become "trapped" at the impurity. This electron may fall back into the valence band again, recombine with a hole, and so complete the cycle. In some materials the donor and acceptor levels may be so close to the band edges that thermal energy even at room temperature is sufficient to ionize them. The donors give up electrons to the conduction band and the acceptors liberate holes in the valence band so that electrical conduction is possible. The material is no longer an insulator but a semiconductor. In the type 2b diamonds, it is the acceptors which are close to the valence band and which make the material a semiconductor. If the impurity levels are more than about one electron volt from the band edges, then thermal effects are ineffective in inducing conductivity.

With these intermediate energy levels and the possibility of trapping electrons and holes at the impurity sites, a great flexibility is introduced into the theory of the properties of solids. Many of the optical properties can be explained. The energy at which absorption will occur is no longer determined by the width of the gap between the valence and conduction bands, but by the kind and number of

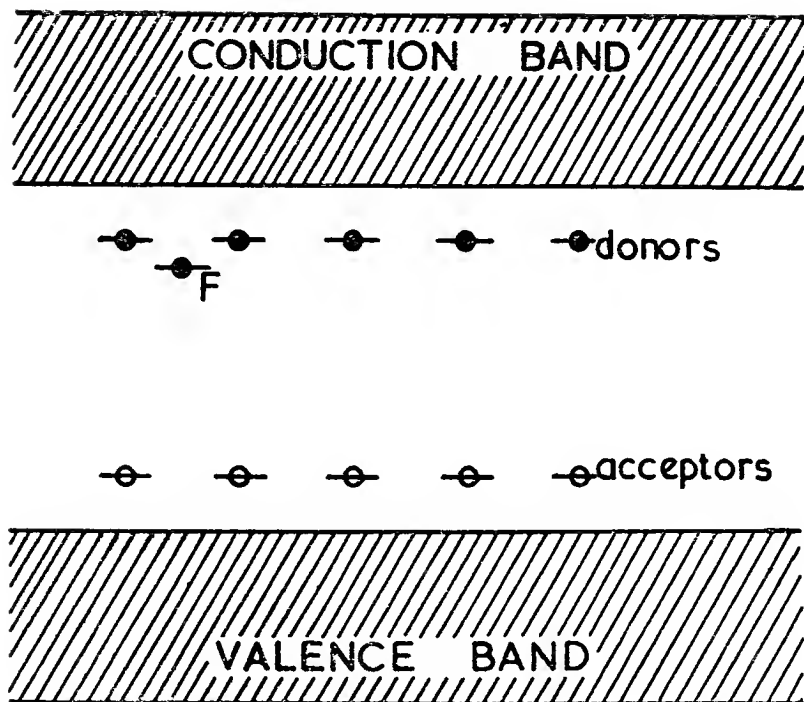


FIGURE 7.

impurities present. It is impurities which change the color of the diamond by introducing energy levels at various heights. Luminescence is likewise due to the type of impurity in the crystal, and photoconductivity can be understood as an electron exchange between the bands and the impurity levels.

The behavior of a diamond when used as a counter is also controlled by the number and kind of impurity. There are about 10^{17} in a cubic centimeter of material. Since there are 10^{23} carbon atoms in this volume, the impurity concentration is one per million. What is of interest is to know at what levels these impurities lie and how one diamond differs from another in this respect. To investigate the energy levels, we have been using beta particles from a Sr^{90} source and then making a systematic survey of the effect of illumination on the counting rate.

A very small hole is made in one of the electrodes and the diamond is irradiated through the hole with beta particles and with a field strength of 10^4 volts/centimeter. A typical counting rate under these conditions is 100 pulses per second. The energy of the beta particle is 2.2 MeV, so that each beta is likely to produce 4×10^5 electron hole pairs, and a little calculation, taking into account the size of the

diamond, shows that we are then dealing with about 10,000 million electrons per square centimeter sweeping through the crystal. They are moving with a velocity of 10^8 cm./sec. and each one is likely to collide with the atoms of the lattice about a million times before being trapped at one of the impurities. Under the influence of the applied electric field, they will have migrated about 0.1 to 1 mm., before being trapped.

The passage of the electrons through the crystal can be likened to billiard balls moving across a very unorthodox billiard table which has not six pockets into which the balls can fall but hundreds scattered at random across the baize. If, in addition, we imagine that the table is hinged at one end and raised at the other, then the slope on the table will be analogous to the effect of the electric field. As the pockets are filled we must imagine the slope on the table to be reduced in just the way that trapped charges reduce the effective electric field by building up an internal space charge.

Only a very small proportion of the traps are occupied in the crystal, and even if free electrons are continually generated at the rate of 10,000 million per second, it would require the best part of a year to fill all the traps. The energy of the beta particles is such that some of them can penetrate right through the small diamonds which we have been using, but the majority of the electron hole pairs are produced fairly close to the electrode through which the particles enter. It is observed that the counting rate, or—what is the same thing—the number of free electrons contributing to the voltage pulses, is not maintained at its initial level. If the experiment is done in darkness, then, after 10 or 15 minutes, the counting rate has dropped to about one-half where it remains steady. To explain this, let us look at the factors controlling the counting rate. In a given diamond it will depend on three things:

1. The number of electrons and holes produced by each incident particle.
2. The value of the electric field in the diamond.
3. The length of time the electrons spend in the conduction band before recombining with a positive hole.

This length of time is called the lifetime. The longer the electron is free to drift through the crystal, the larger is the output pulse obtained. Without impurities the lifetime would be long, because recombinations between electrons and holes will seldom occur by direct collision. A certain energy is required to produce the electron-hole pair, and when they recombine, the energy must be dissipated in the form of irradiation. For the recombination to occur, the electron and hole must be within 2 Å of each other. The characteristic time for radiation is about 10^{-8} sec., which is longer than the time for which the pair are close enough to interact. It is much more probable that

the trapping occurs at impurity centers. The lifetime will then be proportional to the concentration of these.

The falling off in the counting rate must be due to a lowering of the effective electric field inside the diamond. It cannot be due to a change in the number of electrons produced by each beta particle, nor is the lifetime likely to be altered since the number of traps changes very little. What happens is that the trapped electrons or holes produce a space charge in the diamond which has the effect of reducing the electric field. Not many trapped electrons are required to do this. If only 1 trap in 10 million is filled with electrons, it is sufficient to reduce the internal field to zero in the most favorable conditions, but the precise effect will depend on the position of the center of gravity of the space charge. To discover whether a space charge is really produced, the external field was removed when polarization had been established and pulses obtained in the reverse sense were recorded. The diamond continues to count under these circumstances for a few minutes and until the space charge is reduced to a very low value. If the diamond is not bombarded and no electric field is applied, the space charge may persist for a very long time. We have observed it over a period of days. It will be appreciated that the diamond has to be carefully prepared to insure that no residual space charge remains when a series of tests is to be conducted. The procedure which we have found to be the most satisfactory is to irradiate the diamond for 12 hours with no field applied and in the dark before starting an experiment. By this means sufficient free holes and electrons are generated to achieve the equivalent of thermal equilibrium. Only when these precautions are taken are the results reproducible.

Electrons can enter and leave the diamond fairly readily through the electrodes if the diamond has been activated so as to produce free electrons and holes. No particular precautions are necessary to make good contact between the diamond and the metal electrodes applied to it. In fact, if it is suspended on a thread between two metal electrodes, but touching only one of them, then the diamond is found to become charged. The process is quite a slow one and depends on the intensity of the irradiation which, in turn, controls the number of electrons in the conduction band. A diamond suspended in this way is found to swing from one electrode to the other and then back again when it has acquired charge of the opposite polarity.

Let us return to the conventional arrangement of the diamond between two electrodes, and with beta particles entering through a hole in the anode. Most of the free electrons will reach the anode before being trapped, because the electron pairs are produced fairly close to this electrode. The holes, on the other hand, which have to traverse the few millimeters to the cathode are likely to have most of their

number trapped before they reach it. These trapped holes establish a space charge which reduces the electric field in the region where the electron hole pairs are produced. Eventually equilibrium is established when the number of holes which reach the cathode is exactly equal to the number of electrons leaving the crystal. The counting rate is now uniform but at a lower level than initially. Now, what happens if we use infrared light on the diamond? It is found that a polarized diamond at once shows an improvement; the counting rate rises until it is restored to its original value. The same effects are produced as light of shorter and shorter wavelength, i.e., of increasing energy, is used, until at about 6,500 Å a new phenomenon presents itself. Instead of improving the counting rate, light of this energy, or greater, reduces the counting rate. This is the main evidence for two levels of impurities, one of which is essentially a hole trap, and the other an electron trap.

Further information is obtained by irradiating the diamond through the negative electrode. With this arrangement it is the holes which can reach the cathode because of its proximity, while the electrons are trapped as they move toward the anode. The counting rate, the establishment of the polarizing field, and the eventual equilibrium counting rate is found to be much the same as before. It is thus concluded that the density of electron traps and of hole traps is much the same.

Much of the so-called progress in science consists of gathering a few scraps of information and on the basis of these to give one's imagination full rein and so develop a model—a picture—of what is taking place and which will explain the observations. On the basis of this physical model, predictions can usually be made about what may happen under a different set of experimental conditions. We try these new conditions and sometimes receive confirmation of the hypotheses and sometimes see that they must be modified. It is even more fascinating than putting together the pieces of a jigsaw puzzle or solving a crossword.

Omitting the many wrong turnings we made, the following band picture is suggested as best satisfying the results. Near the bottom of the band there are acceptor energy levels, all of which are occupied by electrons. This set of energy levels is probably between 0.8 and 1.2 eV above the valence band. Higher up are a set of donor levels, the greater majority of which have lost their electrons to the acceptors. The energy of this band is about 2.0 eV above the valence band or it might be at 2.0 eV below the conduction band. This point remains to be clarified and the two cases cannot be distinguished at present. In semiconductor parlance, it would appear that the counting diamonds are *p*-type when they are activated. When the beta irradiation enters

at the anode, the holes are trapped mainly in the acceptor levels and the space charge is developed. Subsequent infrared radiation raises electrons from the valence band to these levels occupied by the holes and so reduces the space charge. This explains why the counting rate improves under illumination. If the diamond is bombarded through the cathode, then the electrons are trapped in the empty levels of the donor states. The energies at which these lie are so far from the band edges that infrared light can effect no change in the space charge. This is one of the first tests that was made on the correctness of these ideas and which agreed with the predictions. It also clears up a matter over which disagreement has arisen between experimenters. Some writers have found that infrared improves the counting ability, some that it makes no difference, while yet others reported that it reduced the counting rate. None mentions the electrode through which the diamond was irradiated and which as we now see determines the precise effect. A reduction in the counting rate can easily be imagined if the diamond is bombarded through the negative electrode and had not been carefully prepared beforehand to insure equilibrium conditions with electrons in the lowest permitted energy levels.

When we come to consider the effect of radiation of higher frequency which has sufficient energy to produce transitions to the donor levels from the valence band, our predictions are more tentative. If the effect is to empty a large number of these of their electrons, then a negative space charge will develop and will assume a density in the crystal which is a function of the distance from the anode and thus reduce the effective field considerably and over a large part of the crystal. In fact, instead of about one trap per million being involved in the creation of the space charge as we saw was the case under beta bombardment alone, all of them could now be activated by the high-energy illumination and could swamp the lesser effect of the bombardment. The high-energy light has the same general effect on the counting rate whether the beta bombardment is through the anode or through the cathode.

On an occasion such as this, the speaker is expected to leave his audience feeling that all has been explained, all is known; that the speaker is master of the entire gamut of knowledge. I am afraid that in this respect I must be found sadly wanting, and to one important question I have no answer. I cannot tell you why some diamonds are counters and others are not. However, the interplay of theory and experiment proceeds and I hope that my successor in his inaugural address will express his amazement that we could have been so ignorant of what will then be so well understood.

Seeing the Magnetization in Transparent Magnetic Crystals

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[With 8 plates]

THE metallic magnetic materials iron, nickel, cobalt, and their alloys are within the everyday experience of us all. However, magnetic materials that are not metallic have been the subject of a great deal of study in the past 15 or 20 years. Those which have been most widely studied and used are mixed oxides; i.e., oxides of two or more metals. The technological interest in these compounds arises from the fact that they are exceedingly poor conductors of electricity. Alternating magnetic fields can penetrate them easily. This contrasts sharply with the magnetic metals in which alternating magnetic fields cause eddy currents to flow near the surfaces, and thus shield the body of the metal from the field. This effect becomes more pronounced as the alternating frequency increases, and quite effectively prevents the use of the magnetic properties of the solid metals at ordinary radiofrequencies and above. We will concern ourselves in this paper with a particular class of mixed oxides, the ferrimagnetic garnets, which will transmit radiation up to frequencies in the optical range [1].¹ This specialization should not obscure the fact that there are a number of other transparent magnetic compounds [2]. The term "transparent" should be qualified. These crystals are transparent in that sections 0.005 inch thick or less transmit enough light for microscopic examination. The most satisfactory specimens are about 0.001 inch thick.

The ferrimagnetic garnets were discovered only a few years ago [3, 4]. They have the same crystal structure as the minerals known as garnets; that is to say, they contain oxygen atoms and metal atoms in the same spatial arrangement. However, it should be clearly understood that compounds with the particular combinations of metal atoms with which we are concerned do not occur in nature. The chemical formula [5] of these compounds may be written

¹ Numbers in brackets indicate references at end of text.

$\{M_3\}[\text{Fe}_2](\text{FeO}_4)_3$, where M stands for any one of the following elements: yttrium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, or lutetium. They are called yttrium (or samarium, etc.) iron garnet. In addition, there are a number of other elements which can be substituted in to some degree. Except for yttrium, the metals just listed belong to a group known as the rare earths (or more explicitly as the 4f rare earths). These elements possess remarkably similar chemical properties, and are in fact difficult to separate from each other chemically.

STRUCTURE OF THE MAGNETIC GARNETS

The manner in which we have chosen to write the chemical formula [4a] of the ferrimagnetic garnets $\{M_3\}[\text{Fe}_2](\text{FeO}_4)_3$ is intended to convey some structural information. There are two kinds of sites on which iron ions are located in this structure. They may be at a position in which there are four nearest neighbors, oxygen ions. The centers of these oxygens define the vertices of a slightly distorted tetrahedron. These particular iron ions (in parentheses in the formula) are said to be on tetrahedral sites. For every three iron ions on tetrahedral sites, there are two on octahedral sites. These (in square brackets) are surrounded by six nearest neighbor oxygen ions defining the vertices of a slightly distorted octahedron. Finally, the yttrium or rare earth ions (in braces) have eight nearest neighbors; these sites are called dodecahedral.

All the iron ions in these crystals have a valence of 3, i.e., iron is present as Fe^{++} , and each has associated with it a magnetic moment. We may think of this as a small permanent magnet. Very powerful electrostatic forces called "exchange" forces act to align the magnetic moments of these iron ions. At temperatures near absolute zero, all the moments of the tetrahedral ions are parallel; all the moments of octahedral ions are parallel to each other but antiparallel to the tetrahedral ions. Since for every formula unit there are three tetrahedral and two octahedral ions, the net magnetic moment of the ions in one formula is that of a single iron ion. The moment of a single trivalent iron ion is five times that of a single electron. These units are called Bohr magnetons. Thus, the magnetic moment of an Fe^{++} ion is 5 Bohr magnetons. Yttrium iron garnet at absolute zero has a magnetic moment of 5 Bohr magnetons for each formula as given above. However, the rare earth ions (except Lu) have a magnetic moment. The moments of the rare earth ions are aligned so as to be approximately parallel to each other but antiparallel to the net moment of the iron ions. In several of the rare earth iron garnets at absolute zero, the rare earth magnetic moment is greater than that of the iron sublattice.

It turns out that the temperature dependence [5] of the total iron magnetization is different from that of the total rare earth magnetization. The rare earth magnetization falls off faster with increasing temperature than the iron magnetization. Figure 1 shows how this leads to a magnetization versus temperature curve which changes sign with temperature. Let us say the moment is positive when it is parallel to that of the Fe^{+++} on tetrahedral sites. In the case of yttrium iron garnet, the net moment is parallel to that of the three tetrahedrally coordinated Fe^{+++} per formula unit and thus positive up to the Curie point, the temperature above which the magnetic moment is zero. In gadolinium iron garnet, on the other hand, the moment of the Gd^{+++} ions overrides the net iron moment by a considerable factor. However, as temperature increases, the Gd^{+++} lattice moment falls off faster than that of the Fe^{+++} lattice. At about 290°K . they are equal and the net spontaneous magnetic moment is zero. Above this compensation point, the moment of the Fe^{+++} lattice predominates. The spontaneous moment, that which would be observed in no applied magnetic field, finally decreases to zero at the Curie point. The Curie points of the ferrimagnetic garnets are associated with the exchange coupling of the iron sublattices, and consequently are very nearly the same for all the ferrimagnetic garnets, about 560°K .

CRYSTALS AND SAMPLES

Plate 1 is intended to give some idea of the appearance of the crystals with which we work. In bulk they are shiny and black. In the crystals chosen for photographs, the faces are sharp, well defined, and very nearly flat. Occasionally a variation of the cooling cycle produces a run of crystals which have been etched in some degree by the same melt from which they were grown. There is a tendency for the crystals to be sound near the faces, but in many cases they contain inclusions of the oxide mixture from which they were grown. Sometimes the crystals are cracked. The shiny surfaces invariably have many small etch pits, which can only be seen on examination with a microscope.

We might remark in passing that these crystals [6] are made by heating a mixture of iron sesquioxide (Fe_2O_3), lead oxide (PbO), and the appropriate yttrium or rare earth sesquioxide (M_2O_3). This mixture is heated to about $1,350^\circ \text{C}$., well above the melting point, then cooled slowly. This is done with the mixture in a platinum crucible with a furnace whose temperature can be programmed very accurately.

The growth of crystals involves many difficulties. There are many variables to be controlled or to slip out of control. Large sound crystals are associated with slow cooling rates, uniform cooling rates,

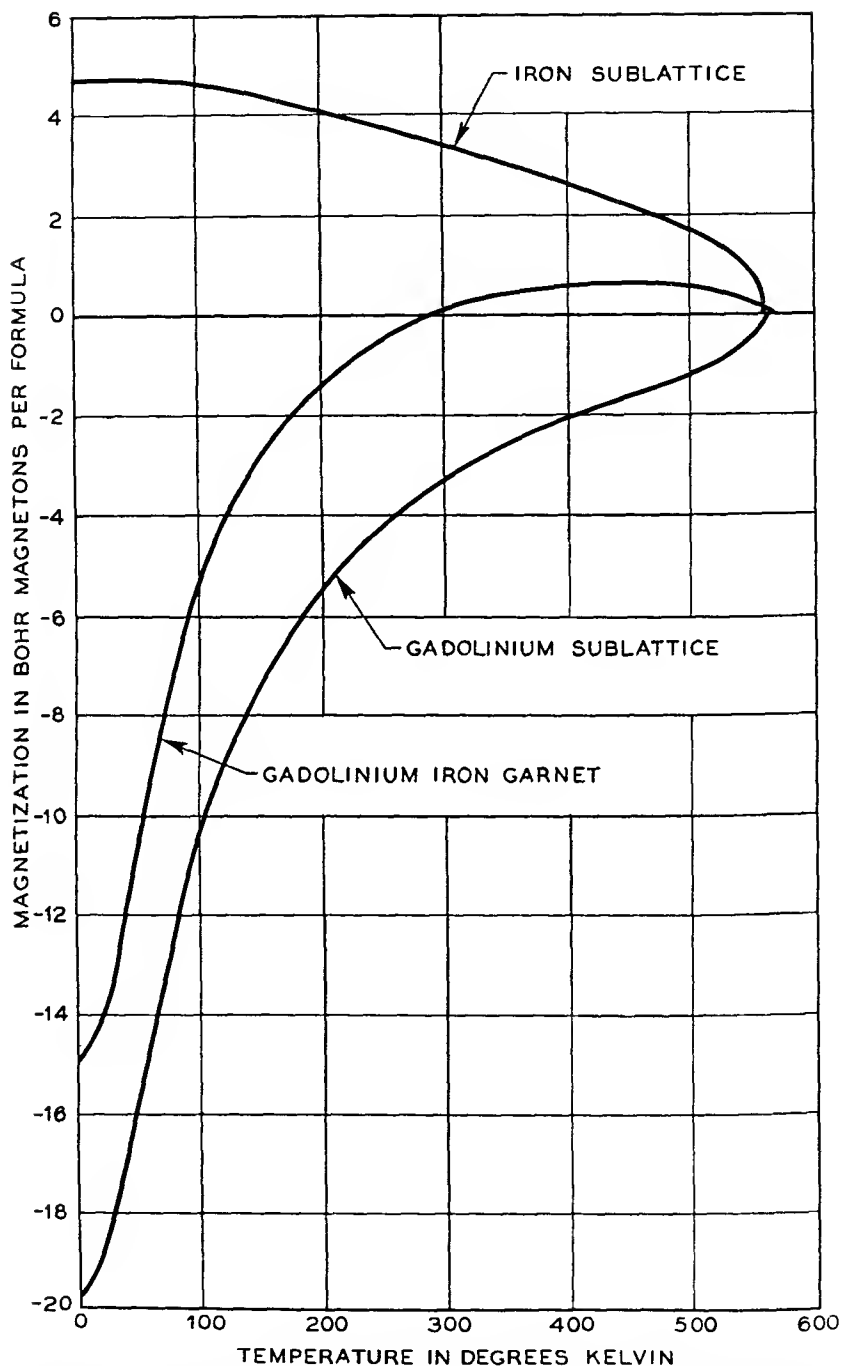


FIGURE 1.—The temperature variation of the magnetization of the iron and gadolinium sublattices in gadolinium iron garnet along with their sum, the net magnetization of the crystal. Adapted from Bertaut and Pauthenet (reference 5).

and large melts. A run in which Nielsen [7] grew some of the large samples took about 3 or 4 weeks to cool. The platinum crucible held a melt weighing about 2 kg. Recently Dr. Lefever of the Hughes Aircraft Co. has pointed out that crystals grown so as to be free of traces of silicon are markedly more transparent than any for which no special precautions have been taken [8].

The preparation of samples suitable to the observation of domains by transparent light is a delicate procedure. If possible, large sound crystals are chosen and slices of the desired orientation are sawn off with a water-cooled circular diamond saw. These are, say, 0.015 to 0.020 inch in thickness. The slice is waxed down to a holder and polished. The block is heated, the sample reversed, and the opposite side is polished down to within the desired thickness of the first side. If the crystal is to be viewed without further treatment, the best thickness is about 0.001 inch thick. Sometimes a growth face has been left as one side of the finished specimen. Samples which are to be etched down to a convenient thickness after polishing are, of course, considerably thicker.

The procedure used to polish a sample has been, and will surely continue to be, subject to improvements. It consists of grinding with a rather fine abrasive, American Optical Co. 303½ emery, well past the surface produced by any coarser abrasive. The polishing is done with a slurry of Linde A alumina with a particle size of 0.3 micron. About 0.002 inch of material is removed in this polishing past the bottom of the pits left by the 303½ emery. In some variations of the procedure, diamond paste is used; in some, great pains are taken to reduce the weight on the surface of the sample.

OPTICAL PROPERTIES

We must examine two optical properties in order to understand the visibility of the magnetic domains [9]. The first of these is the absorption. Light entering a medium is attenuated exponentially with thickness. This is given by the Beer-Lambert law for the ratio of the intensity I after traversing a thickness t to the incident intensity I_0

$$\frac{I}{I_0} = e^{-\alpha t}.$$

The constant α is called the absorption coefficient and it varies with wavelength. Figure 2 shows α in the visible portion of the spectrum. It is smallest at the red end of the visible, rises to a peak in the yellow, falls, then goes offscale upward in the green. A low value of α means a high fraction of the light is transmitted, and a high α means a small part is transmitted. For the thinnest samples we have been able to make, it has not been possible to get a measurable transmission for light much past the green shown on the plot.

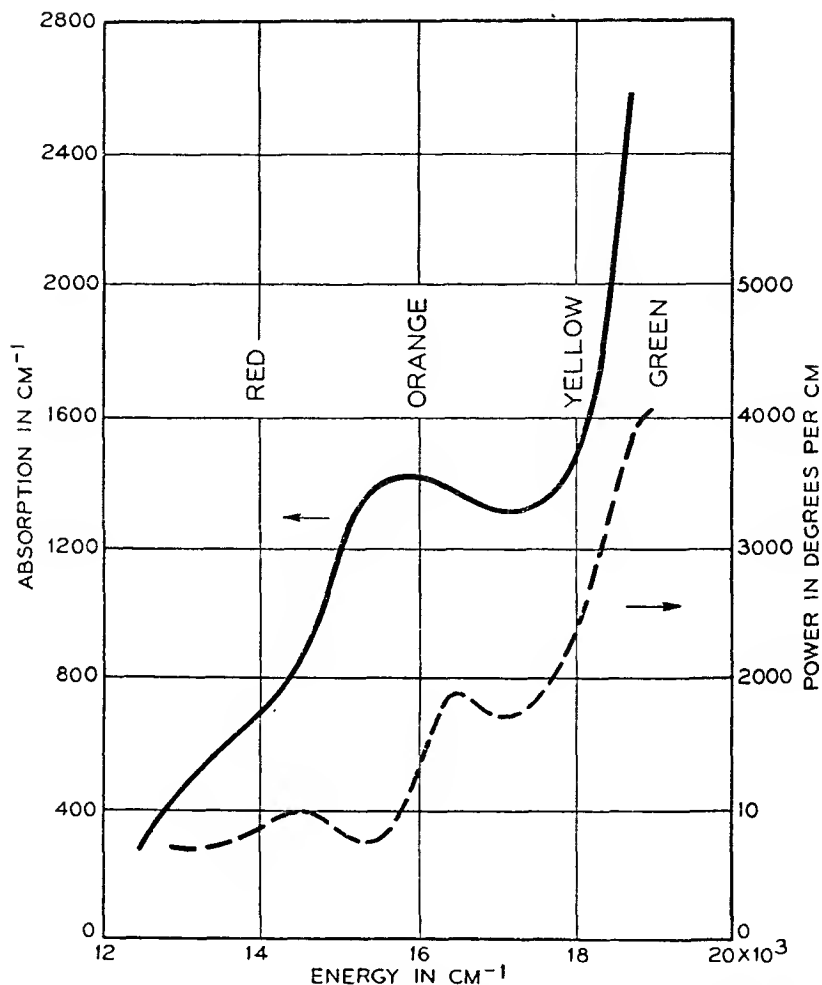
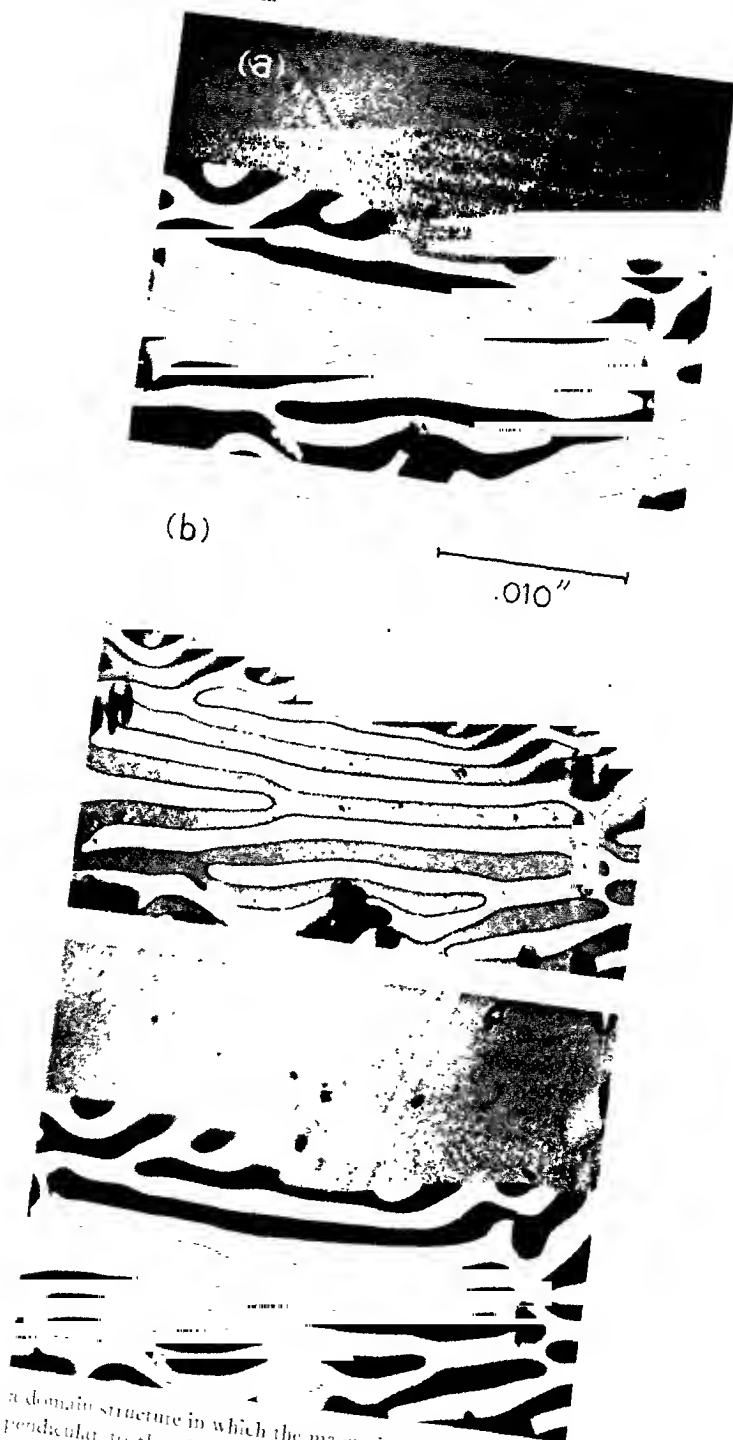


FIGURE 2.—The pertinent optical properties of yttrium iron garnet. The solid line is the absorption, and the dashed line, the rotation per centimeter of the plane of polarization of light passing through the crystal with the magnetization along the line of sight.

The second optical property of interest is the rotation. If plane polarized light is incident on one of these thin samples, we find that on emergence the plane of polarization is rotated. But this rotation is of a very special sort: it is nonreciprocal. It depends on the orientation of the magnetization within the part of the crystal through which the light passes. If the magnetization is parallel to the path of the light, the plane of polarization is rotated through some angle θ , but if the magnetization is antiparallel to the optical path, the angle is $-\theta$. Finally, if the magnetization is perpendicular to the optical path, there is no rotation at all. To measure the specific rotation, then, we must aline all the magnetization within the sample and make it,



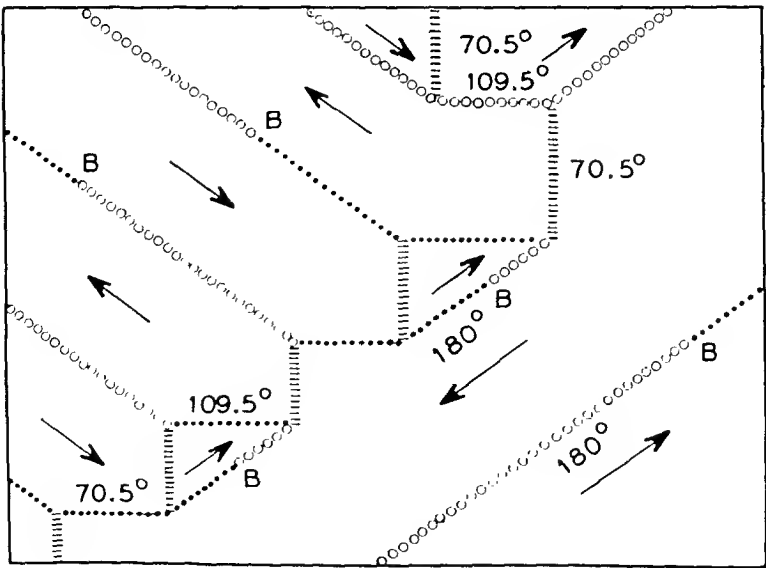
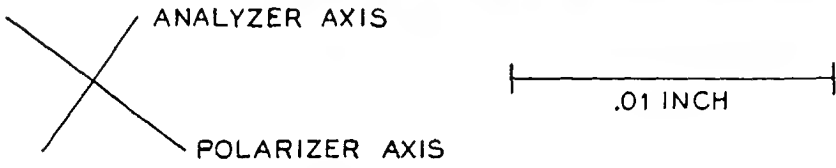
Photographs of some rather large and sound yttrium iron garnet crystals grown by J. W. Nielsen.



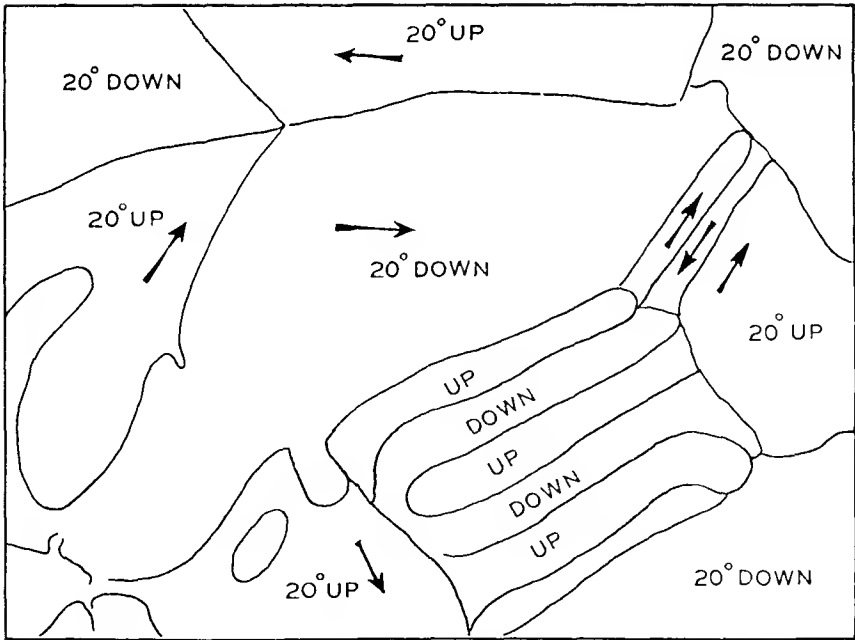
Photographs of a domain structure in which the magnetization lies in the plane in the upper half, and perpendicular to the plane toward and away from the observer in the lower half. The three photographs correspond to the three settings of the analyzer in figure 3.



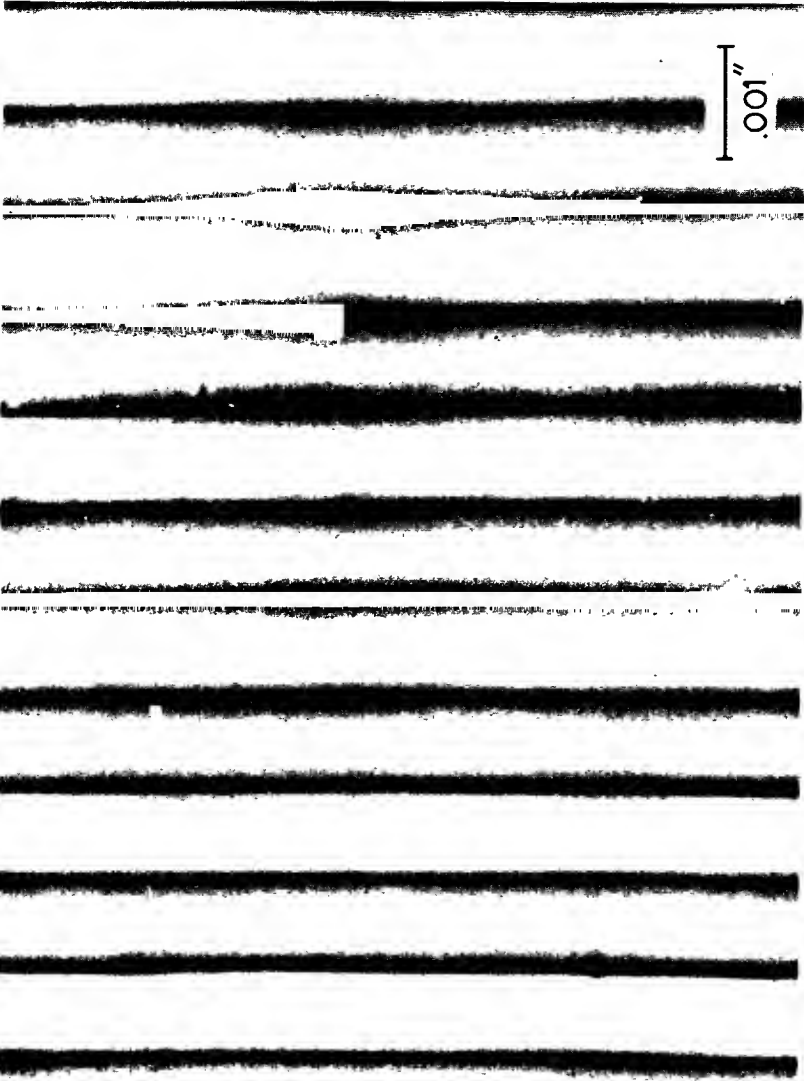
A color photograph of domains in an yttrium iron garnet single crystal. The analyzer was somewhat off the setting which corresponded to extinction without the crystal. This was taken by W. Vandivert for the *Scientific American* under the author's direction.



Domain structure in a thin section of yttrium iron garnet, the crystal plane of which is perpendicular to the face diagonal. (See figure 6) The contrast between the domains whose magnetization is parallel and not parallel to one of the polarizer-analyzer axes arises from the magnetic birefringence.

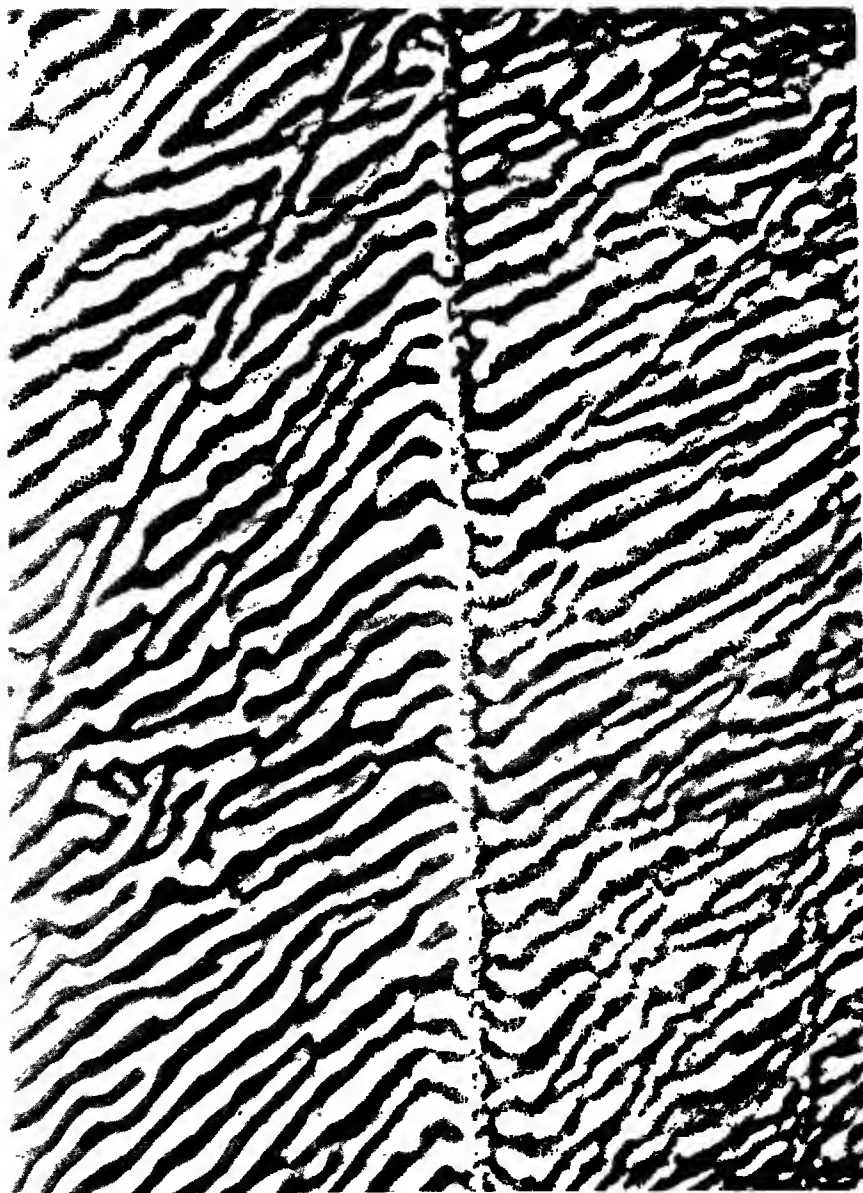


A region in a gadolinium iron garnet crystal in which the magnetization lies along many of the possible body diagonal preferred directions. The plane of the crystal is perpendicular to a three-fold axis. (See figure 7)



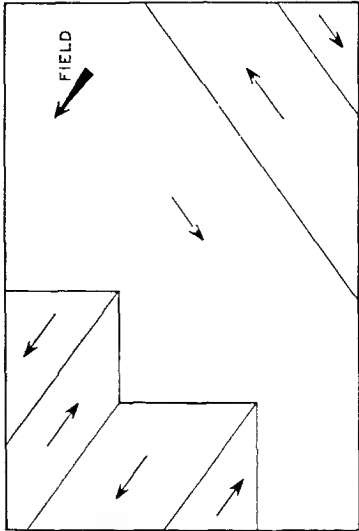
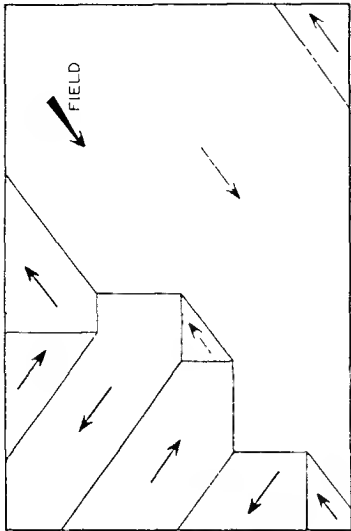
0.01"

A region in an yttrium iron garnet crystal in which the magnetization lies up and down in long straight ribbon domains. Analyzer and polarizer are crossed so the walls appear as black lines.

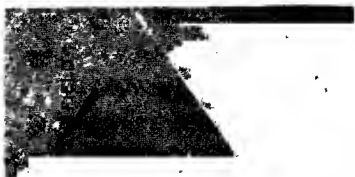



 0.1MM

Magnetization structure around a scratch in a badly strained yttrium iron garnet crystal. Note the way in which the structure near one surface is out of register with that on the other.



— .01 INCH



ANALYZER AXIS

POLARIZER AXIS

The domain structure of plate 4 was disturbed by applying small magnetic fields along two of the easy directions. Here we can see the way in which the domain walls move so that favored domains grow.

say, parallel to the line of sight. When this was done, and the angle of rotation per unit thickness measured for light of various colors, the specific rotation curve of figure 2 was obtained. This also shows some structure and it is clearly related to that of the absorption curve. The rotation is least in the red, and greatest near the absorption edge in the green.

It might be remarked parenthetically that a great deal of the basic scientific interest in these transparent crystals arises from the fact that we are able to measure the structure in the absorption and rotation curves out to the middle of the visible spectrum. The peaks in α here and others in the near infrared represent electron transitions involving the electrons responsible for the magnetization of these crystals. The rotation very clearly demonstrates the involvement of the magnetization. It is believed that the transitions involved in both the rotation and the absorption are between levels of the iron ions in octahedral sites. It is not the total magnetization that is important in determining the sign of rotation, but the direction in which the magnetization of the octahedral Fe^{+++} lattice lies.

DOMAIN VISIBILITY

How, precisely, do we see the distribution of the magnetization in one of our little transparent samples ? [10] Figure 3 illustrates this. Consider a hypothetical crystal in which the magnetization is distributed in three sections: parallel, antiparallel, and perpendicular to the line of sight, as shown in the figure. Before passing through the crystal, the light goes through a polarizer. Consider the red light and the green light separately. Passing through regions (*a*) and (*b*), the planes of polarization will be rotated in opposite senses, and the net rotation for the green will be much greater than that for the red. The light which passed through (*c*) will not be rotated at all. However, in every case the green will be considerably more attenuated than the red.

Now compare three settings of a second polarizer, traditionally called the analyzer, and the corresponding appearance of the magnetization. If the analyzer is set at the angle which corresponds to extinction without the sample, light passing through region (*c*) is not rotated at all, and thus (*c*) appears black. However, the red light going through (*a*) and (*b*) is rotated slightly, and the green light about three times as much. Because of the greater angle for the green, we see these regions as bright green. However, in the narrow band between (*a*) and (*b*) the magnetization makes a smooth transition between parallel and antiparallel to the line of sight. In the center of this the magnetization lies in the plane, and thus it, like region (*c*),

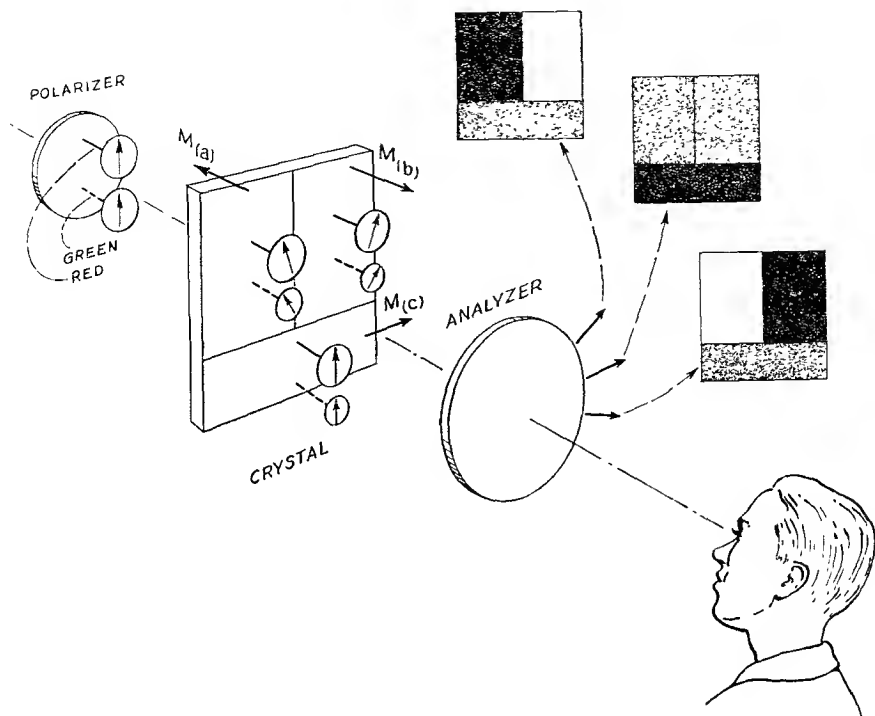


FIGURE 3.—A schematic representation of the mechanism whereby we see the disposition of the magnetization with a transparent magnetic crystal.

appears black. If the analyzer is turned so that the green light going through (a) is extinguished, the region (a) will appear dark red, and (b) will be a pale red or yellow. Region (c) will be of some intermediate shade. Similarly, by turning the analyzer to the other side of the original extinction, setting (b) can be made to appear dark, and (a) light, with (c) an intermediate shade. Clearly, there is a continuous range of settings possible, and those just mentioned are merely easily defined cases.

Plate 2 shows photographs of a crystal containing areas of parallel, antiparallel, and transverse magnetization viewed with the analyzer at three different positions.

Plate 3 is a color photomicrograph showing the distribution of magnetization in a crystal of yttrium iron garnet. The analyzer was set slightly off the original extinction so that it is possible to distinguish between regions in which the magnetization is pointing toward the observer from those in which it is pointing away. These are the dark green and yellow bands. The large red bands are regions in which the magnetization lies in the plane. Figure 4 shows the disposition of the magnetization in the crystal.

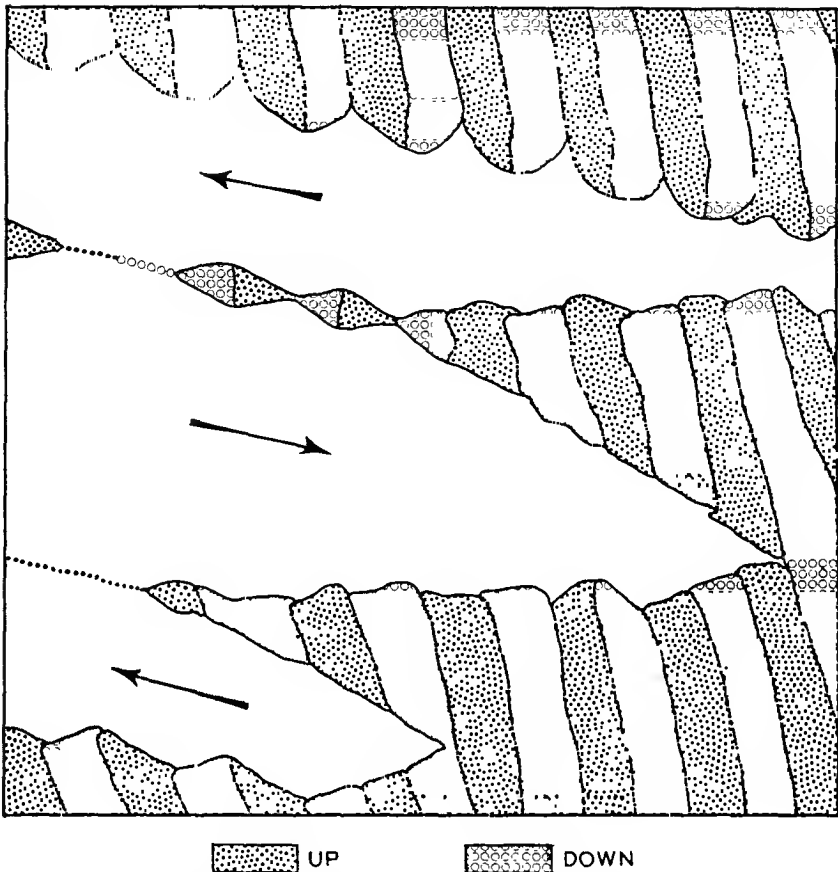


FIGURE 4.—Key to plate 3 showing the direction of the magnetization in each of the domains.

The discrete regions in each one of which the magnetization is directed in a distinct direction are called domains. The transitions between adjacent domains are called domain walls.

Many years ago the concept of domains was put forth by the French physicist Pierre Weiss [11] to account for the puzzling behavior of magnetic materials. The facts were these: A piece of a ferromagnetic material in the absence of an externally applied magnetic field showed no magnetic moment. However, the application of a relatively small field seemed to induce a very large moment. Application of fields above some "saturating" value seemed to have no further effect. Weiss proposed that the material was broken up into "domains" in each of which the material had its maximum magnetization for the temperature prevailing. He suggested that large internal "molecular fields" kept the magnetization aligned within the domains. The application of magnetic fields was thought to cause

some domains to grow at the expense of others having a less favorable orientation, and also in some cases the magnetization direction within a domain was thought to rotate to a more favored direction. This remarkable insight antedated the observation of domains by about 25 years.

In addition to the magnetic rotation of the plane of polarization, we can distinguish between some domains lying in the plane perpendicular to the line of sight by a magnetic birefringence. A thin section of a crystal can be seen to be birefringent if, when it is placed between crossed polarizers, the light is no longer extinguished except at certain angular settings of the crystal. This happens because the crystal transmits light polarized along one crystal direction at a velocity different from that at which it transmits light polarized along a perpendicular direction. If light entering the crystal is plane polarized exactly along one of these axes, the emergent light is plane polarized and can be extinguished by a properly set analyzer. If the light entering the crystal is plane polarized but not along either of these axes, the emergent light is elliptically polarized and cannot be completely extinguished by an analyzer.

In the present case it is found that domains whose magnetization lies in the plane show a birefringence. This is called a magnetic birefringence, since it is associated with the magnetization. If the direction of polarization is parallel or perpendicular to the magnetization, the emergent light can be extinguished by the analyzer. If the plane of polarization is neither parallel nor perpendicular but at some other angle to the magnetization, the light passing through cannot be quite extinguished by the analyzer. The effect is a very feeble one and the distinction can be made only if domains with two headings of the magnetization are present. Figure 5 illustrates the manner in which a contrast between the two domains is achieved. Note that light and dark can be interchanged by rotating the crystal through an angle equal to that between the magnetization directions. In the case of domains which we can distinguish by virtue of a difference in the rotation of the plane of polarization, light and dark can be interchanged by moving the analyzer to the opposite side of the original extinction position; rotation of the crystal between polarizers has no effect on the contrast. Plate 4 shows a domain structure seen by virtue of the birefringence.

DOMAIN STRUCTURE

It is a general physical principle that a system assumes the lowest free energy state accessible to it [12, 13, 14]. The magnetization distributions which we encounter here or in any other sample are the result of minimizing the total magnetic energy of the crystal. It is

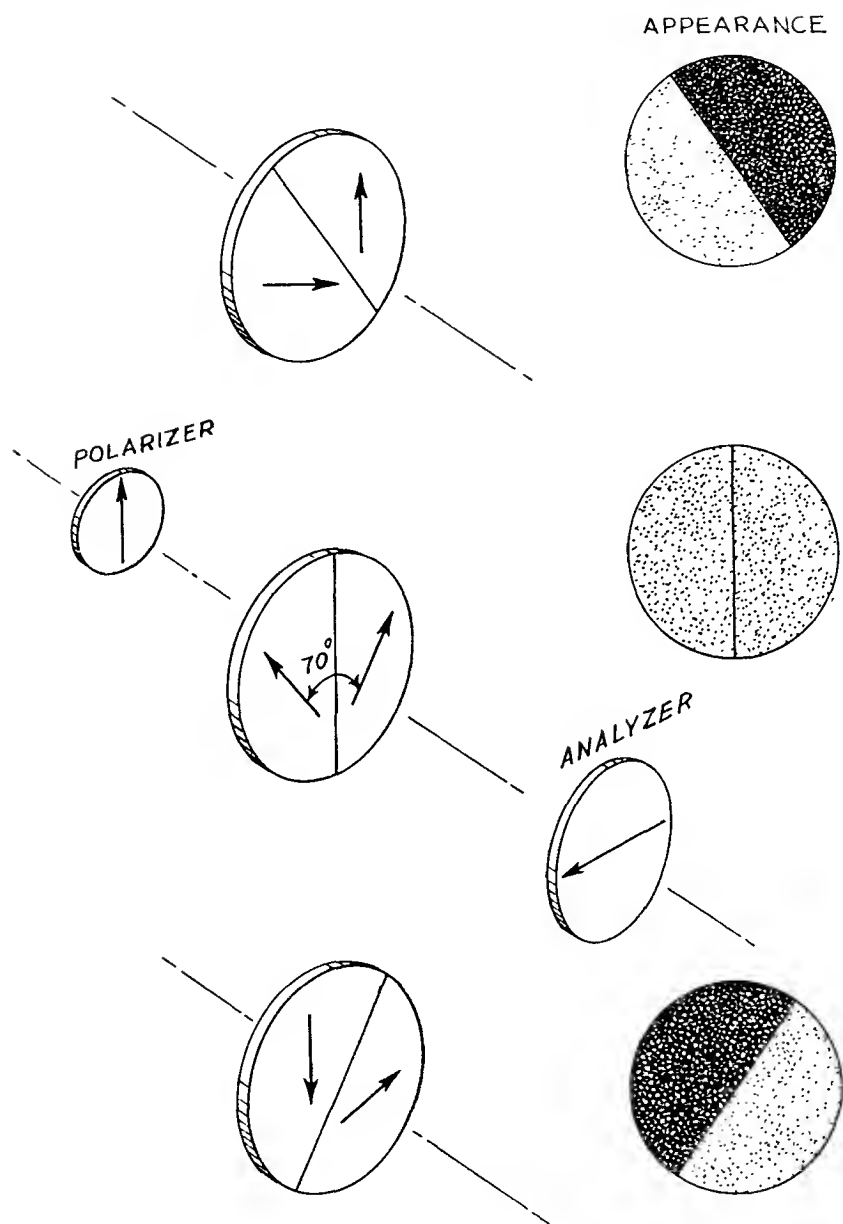


FIGURE 5.—A schematic representation of domain visibility by virtue of the magnetic birefringence.

possible to break this total magnetic energy down into several components. These are—

- (a) Exchange energy,
- (b) Magnetocrystalline anisotropy energy,
- (c) Magnetostrictive energy,
- (d) Demagnetization energy.

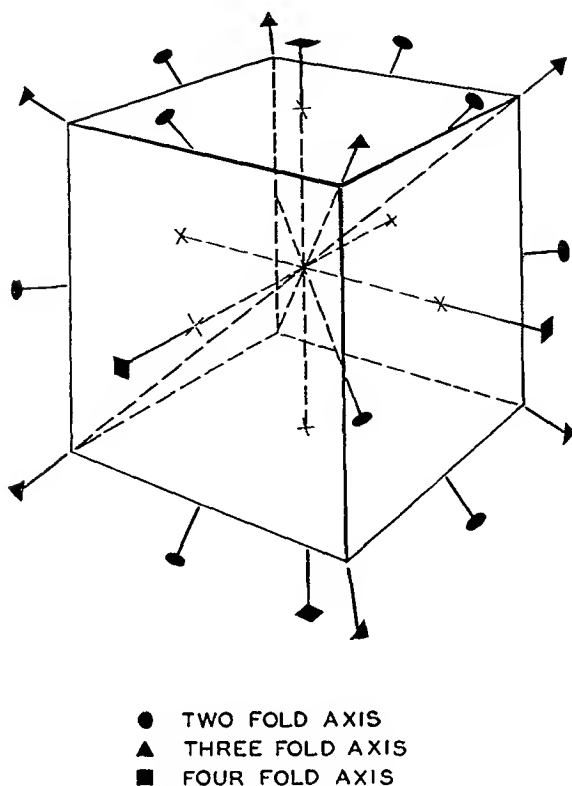


FIGURE 6.—The rotational symmetries of a cube. Except for the magnetization itself, which does define a unique direction, the ferrimagnetic garnets have these symmetries.

We will discuss each of these and show the relation to domain structures observed in the transparent magnetic garnets.

The exchange energy is a minimum if all the net moments of neighboring unit cells are exactly parallel to each other. It would be prohibitively large if neighboring cells were to have their moments antiparallel. The result is that if for some other reasons the magnetization must lie along different directions in different parts of the crystal, the transition from one direction to the other is spread over many cells. The exchange forces are short-range forces. Very little energy is involved if parts of the crystal with different directions of the magnetization are far removed from each other.

The garnet structure has the symmetry of a cube. A cube has several rotational axes of symmetry. It can be rotated one-quarter of a turn about any of three mutually perpendicular axes, and it will come back to a position indistinguishable from the original. These fourfold axes are parallel to the cube edges. A cube can be rotated one-third of a turn about any of the four body diagonals, and it will come back on itself. These are the threefold axes. This is only a

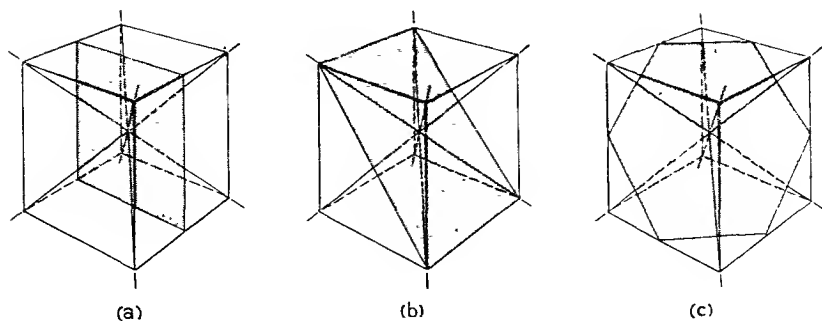


FIGURE 7.—The magnetization in the magnetic garnets prefers to lie along the body diagonals of the cube which represents the symmetry of the lattice. This figure shows how these body diagonals are disposed relative to any one of the principal planes of the symmetry cube.

partial list of the symmetry elements of the cube and of the garnet structure. Figure 6 indicates the fourfold, threefold, and twofold axes of a cube.

On examination of the magnetic properties of a single crystal, it is invariably found that the magnetization prefers to lie along certain crystal directions. In iron, a cubic crystal, for instance, these preferred directions are parallel to the edges of the cube. In yttrium iron garnet, the preferred directions are the body diagonals of the cube; that is, the threefold axes. There are four body diagonals, and the magnetization can point either way along each of these; thus there are eight so-called easy directions. To pull the magnetization out of the easy directions requires the expenditure of work. With any crystallographic direction we can associate an energy, thus defining an energy surface. This is called the magnetocrystalline anisotropy energy. If any part of the volume of a crystal has its magnetization along some other than easy direction, there is a contribution to the anisotropy energy and thus to the total magnetic energy. Figure 7 shows the three so-called principal planes of a cubic crystal with the body diagonals drawn in. In (a) the plane perpendicular to the fourfold axis contains no easy directions; they lie some 35° above and below it. In (b) we see that there are two easy axes in the plane perpendicular to the twofold axis. They make an angle of about 70° with each other. Finally, the plane perpendicular to the threefold axis has one easy axis normal to it, and three others about 20° out of the plane.

Plate 5 shows a crystal fragment of gadolinium iron garnet in which the magnetization in various domains lies along almost all of the possible body diagonals. The plane of the crystal is perpendicular to the threefold axis, as in figure 7(c). The line drawing shows the orientation of some of the domains.

In a sample which is not clamped, there are dimensional changes associated with the magnetization along some crystal direction. If the sample were clamped so that its surfaces could not move, magnetizing it would introduce large stresses within the material. This coupling between the elastic properties of a magnetic crystal and its magnetic properties is termed "magnetostrictive coupling," or magnetostriction. If a sample is stressed, extra terms are added to the magnetic energy. It is as if additions were made to the magnetocrystalline anisotropy energy. However, whereas in these crystals the anisotropy energy is cubic, a stress might act along a single direction or be uniform within a plane; thus the stress-induced extra anisotropy might make a certain direction the preferred direction, or might make the magnetization prefer to lie perpendicular to a direction. The dimensional changes associated with magnetization are only one or two parts per million in yttrium iron garnet.

This is all very pertinent to the domain structures we see here because the samples are easily strained. In fact it is very difficult to obtain samples which are not strained in such a way as to strongly affect the magnetization. The mechanical polishing procedure described briefly above seems to leave the surface of the crystal strained. The result is that there is a stress-induced easy direction of magnetization normal to the surface. If there are areas of greater strain than others such as might be expected below a place where a scratch from a coarse abrasive was polished out, there will be special forces on the magnetization in that region. If the stress is relatively uniform over the surface, the domain structure will consist of fairly simple patterns—long sections of straight parallel walls are typical, though very interesting patterns can be obtained. Plate 6 is an example of such a structure. If, on the other hand, the effects of local strains are large, the pattern will be irregular. It might well be that there are regions in which the domain walls, starting from the bottom surface, are out of register with those near the top surface. Plate 7 shows the domain structure seen in a crystal which is badly scratched. In addition to the main scratch, it will be seen that there are several other distinguishable lines which seem to prefer to have a domain wall along them. These represent the stressed volume of material below a scratch which has been polished out at least until the surface is smooth.

Some of the strain with which we must reckon arises in the growth process of the crystal. As far as we know, no one has yet been able to produce a specimen in which the domain structure was not in some degree determined by the state of stress of the sample. However, by etching away the mechanically polished surface, it is possible to achieve patterns which are not completely dominated by this surface

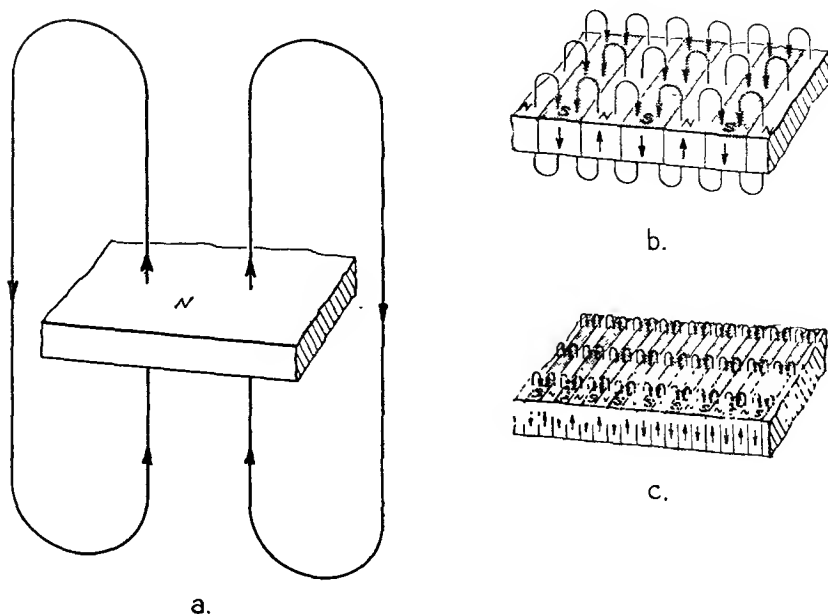


FIGURE 8.—Possible magnetization distributions in a crystal in which the magnetization is constrained to lie perpendicular to the surface.

strain. In such a specimen the domain structure is fantastically fragile. Merely touching the crystal with a single bristle from a fine camel's-hair brush will completely alter the structure observed. Stretching or compressing or bending any of these samples will radically affect the magnetization. If a simple stress is applied, the effects can often be easily understood.

Consider a crystal plate which suffers from a uniform surface compression as just discussed, such that its easy direction of magnetization is perpendicular to the faces. Why is its magnetization not merely all in one direction in one domain the size of the crystal as in figure 8(a)? The answer lies in the minimization of what is called demagnetizing energy. If a sample has the magnetization as in figure 8(a), there is a magnetic field extending out into space around the sample. It requires energy to set up a magnetic field in space—so-called field energy, and it depends on the strength of the field and the volume of space. If the magnetization breaks up into a ribbon pattern as in figure 8(b), the intensity of the fields involved will be about the same, but they will fill a much smaller volume of space. Thus by breaking up into ribbon domains, the field energy part of the total magnetic energy has been drastically reduced.

The reader might ask why the process does not continue, say, to the condition (c), where the ribbons are even smaller and the field energy is even lower. It turns out that the domain walls have energy,

and that this is constant per unit area. As we increased the number of ribbon domains, we would increase the total wall energy. Somewhere there is an optimum spacing where the total energy is a minimum, and this is the stable spacing. In these crystals the spacing depends on the thickness, and on the magnetization. If we decrease the thickness, the ribbons become narrower; if we increase the magnetization, the ribbons become narrower. Suppose the magnetization were decreased to zero. Then there would be no fields associated with a configuration such as that in figure 8(a), and it would be the stable domain configuration. Referring back to figure 1, we see that for gadolinium iron garnet there is a compensation point just a little below room temperature. It is merely necessary to cool the sample about 10° C. to get so close to the compensation point that the magnetization is negligible, and very large areas replace the ribbon domains.

The part of the energy of which we have just been speaking is often termed the "demagnetizing energy," since its minimization always tends to demagnetize magnetic bodies. The fields are "demagnetizing fields." The effect obviously has a great deal to do with the shape of a sample, and with the direction within the sample along which the magnetization chooses to lie.

DOMAIN WALLS

Let us change our frame of reference slightly and consider the domain walls as entities. Of what do they consist, what are their energies, and what is their importance? Figure 9 is a schematic representation of the magnetization distribution on passing through a 180° domain wall; that is, a wall on one side of which the magnetization is antiparallel to that on the other side. In the domains on each side of the wall the magnetization lies along an easy direction, and neighboring volumes have their magnetization parallel. But within the wall there is a volume of material which has its magnetization along other than easy directions; thus the wall must have associated with it a certain amount of anisotropy energy. This part of the energy could be reduced by making the wall thinner, for then the total volume of magnetization out of an easy direction would be reduced. If the wall had no thickness, it would have no anisotropy energy. But we remarked much earlier that if it had no thickness, the net magnetic moment of neighboring cells would be antiparallel and would have a prohibitive exchange energy. The total exchange energy can be reduced by making the angle between the magnetization of adjacent volume elements as small as possible. Thus the exchange energy would be a minimum for an infinitely thick wall. Here we have two energy conditions, one forcing the wall to be

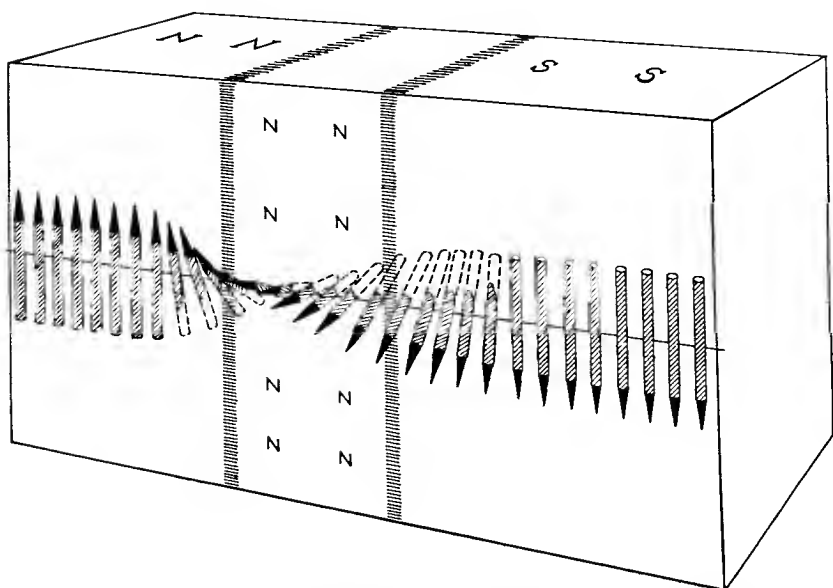


FIGURE 9.—An indication of the way in which the magnetization direction varies on passing through a 180° domain wall.

thinner, and the other forcing it to be thicker. The actual thickness, of course, depends on the size of the maximum anisotropy energy for the crystal at that particular temperature and the size of the exchange energy. For yttrium iron garnet at room temperature, we would expect the wall to be about 7,000 Å thick. This is equal to 550 times the lattice constant, the edge of the cubic unit cell.

If there are neighboring domains in which the magnetization is directed along two different easy directions, a little consideration will show that in these crystals we could have 180° , 110° , and 70° walls. In crystals in which the polishing strain determines a single easy axis, there are only 180° walls. The geometrical situation is considerably more complicated in the general case, since it is necessary to take into account the crystal plane in which the wall itself lies.

Note in figure 9 that the wall is drawn so that the magnetic moments are always parallel to the plane of the wall. If they were not, there would be a large magnetostatic energy associated with the wall in the same way as that of the single large domain in figure 8. The stringency of this condition varies as the magnetization, and when the magnetization approaches a compensation point it disappears altogether. Thus in gadolinium iron garnet at 14° C., the angular variation of, say, the octahedral iron magnetization is somewhat different from that in the yttrium iron garnet at the same temperature.

The expected domain wall thickness in our samples is somewhat

less than a wavelength of visible light. This means that with an optical microscope we cannot resolve any structure within the wall. We might be able to see the wall, and determine whether the magnetization is up or down, but it is unreasonable to expect to be able to see anything meaningful about how the magnetization is distributed within it or, for example, how thick the wall is. Anything which looks like structure within the wall or a clear-cut thickness in our photographs is probably an artifact.

The manner in which the magnetization varies across the wall depicted in figure 9 is like a right-hand screw. It could equally well have been like a left-hand screw. However, we can visually distinguish between these two cases. Note that at the center of the wall in figure 9 the magnetization is directed forward. If it were a left-handed wall, the magnetization would be back along the middle of the wall. By setting the analyzer off the original extinction setting, we can make these two wall segments appear light and dark. There are several examples of this in the photographs shown in this paper. Plate 3 has a 180° domain wall between domains in the plane which alternates from right to left handed. The boundaries between right- and left-handed wall segments may be regarded as entities in themselves. They are known as Bloch lines, and have an energy per unit length associated with them. Plate 8 contains a very simple example of a wall in two segments of opposite sense separated by a Bloch line.

If there is an energy per unit area associated with a domain wall, the wall energy can always be reduced by decreasing the area of the wall. Thus it tends to stretch tight if possible. This "surface tension" is exactly comparable with the surface tension observed in a soap bubble. Similarly in the case of the Bloch line, the line acts like an elastic string under tension always trying to decrease its length.

CONCLUSION

The domain theory view of the magnetic properties of ferromagnetic materials is by no means the most sophisticated. However, it is a great deal more fundamental than that in which the magnetic induction versus field relationship is merely tabulated and characterized for a range of technologically interesting materials. Unfortunately, in many cases this latter has been the basis of teaching ferromagnetism. The macroscopic magnetic properties of most specimens may be considered as arising from the domain structure that prevails and from the hindrances to its alteration [15]. A soft magnetic material shows a high permeability at low fields, and its entire induction can be reversed fairly easily. These are the materials for transformer cores, inductors, and so on. An example of this is the part of plate 3 in

which the magnetization lies in the plane. Here the application of exceedingly small fields in the plane of the sample moves the intervening 180° wall, and thus the total magnetization is very responsive to the field. Hindrances to wall motion, such as actual holes in the material, inclusions of some other compound, overall strain, or a small highly strained region, modify this responsiveness very markedly. All these effects can be seen in some degree in these transparent magnetic garnets. None of our samples ever becomes magnetically "hard" in comparison with magnetoplumbite or ferroxdure. However, the contrast between samples with one or more of the hindrances mentioned and samples in which the walls can move freely is very clear and instructive.

The transparency and magnetic rotation in the ferrimagnetic garnets enable us to see many of the characteristics of domain structure in what are perhaps our best experimental magnetic specimens at this time. From the point of view of demonstration and illustration, one can see manifested in these domains and the way in which they behave with field temperature, strain, etc., all the factors that determine the magnetic behavior of a material, in addition to its own interest. The ability to see the magnetization has proved to be a valuable tool in fundamental magnetic research.

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Biophysics of Bird Flight¹

By AUGUST RASPET²

[With 2 plates]

THERE is no doubt that modern mechanical flight owes its inspiration to observations of birds in flight by early philosophers and scientists as well as by interested laymen. The earliest living "flying machine" is dated about 150 million years ago. This was the pterodactyl of geologic times. In contrast, manmade flying machines are only 57 years old. You can see from this contrast of eras that we may look for new knowledge of flight from a study of this age-old concept of bird flight.

In Greek mythology, the story of Daedalus and Icarus is well known. Daedalus designed and built, supposedly, two flying machines, covered with feathers, using a structure of wax to support them. This was really a mythical imitation of bird flight. There was no application of real knowledge of the mechanism of bird flight, merely an imitation, in form, but not in function. But, of course, not having this knowledge, we, even today, cannot duplicate bird flight in the sense of straight imitation on a scale such that a man can fly as a bird does, by his own muscle power.

The first known flying machine constructed on bird-flight concepts was Da Vinci's well-known invention. About 1505, Da Vinci test-flew this machine, using a test pilot, as is common practice today. The results are indicated in Da Vinci's notebooks by the fact that after this test flight there was no more mention of flying. There is rumor that the test pilot broke his leg. The test pilot, in this case, was one of Da Vinci's household servants (pl. 1).

It was Lilienthal [1]³ who also imitated bird flight, even to the point of using such small stabilizing tail surfaces that his machine was only marginally stable. But we must remember that it was also Lilienthal who, by this bird imitation, proved Newton, Kirchhoff, and Helmholtz to be wrong in their concept that lift is generated by a downward de-

¹ Reprinted by permission from Science, vol. 132, No. 3421, July 22, 1960.

² The author, at the time of his death on Apr. 27, 1960, was head of the Aerophysics Department of the Engineering and Industrial Research Station, Mississippi State University, State College.

³ Numbers in brackets refer to list of references and notes at end of article.

flection of the air, simply as a reflection phenomena, and in disregarding entirely the suction on the upper surface. For his failure to understand that birds possess automatic stability due to instinctive reflexes, in addition to that inherent in their geometry, Lilienthal paid with his life.

The realm of bird flight can be clearly divided into two aspects: that on motionless wings, which is soaring, and that on flapping wings, which is really the working part of flight. The latter is used in take-off and in climbing to altitude, even by soaring birds. It is used as a principal mode of flight by the nonsoaring birds. The soaring phase of flight, or the flight on motionless wings, was divided by Lord Rayleigh in 1883 [2] into three separate categories: (i) Flight in which the path is not horizontal—in other words, gliding; (ii) flight in an air mass which has a vertical component—that is, static soaring; and (iii) flight in an air mass which is not uniform in velocity. The latter is, in the strict sense, dynamic soaring. Evidently, a good understanding of the first phase, the motionless wing phase, would contribute much to an understanding of the biophysics of bird flight. The second kind of flight, much more complicated (flapping flight), has been theoretically studied, but very little experimental work has been done to support the various theories. It is the purpose of this article to take up in detail the aerodynamics of a bird's wing—in particular, that of motionless wing flight.

WIND-TUNNEL EXPERIMENTS

When we consider the various tools available to us for studying flight in general, we are apt to resort to the one which has been so useful in helping man to fly—namely, the wind tunnel. It was a wind tunnel which helped the Wright brothers to arrive at proper airfoil sections, and the wind tunnel is still used today for subsonic, transonic, supersonic, and hypersonic flow studies. It will be interesting, therefore, to look at some results from wind-tunnel work on the measurements of bird aerodynamics and compare these results with some data obtained in flight. From this, we can determine the validity of the wind tunnel in bird-flight work. In figure 1 is shown a velocity polar of a laughing gull, computed from data measured in the wind tunnel and data measured in flight. The velocity polar is clearly seen to consist merely of a plot of sinking speed, which is really a measure of the energy loss in flight, versus the forward velocity of flight. Actually, this is not a polar, but the terminology is that which is used in aviation. It should be mentioned that the laughing gull measured in the wind tunnel [3] was not actually a feathered bird, but rather a clay model sculptured by an artist. The tunnel, however, possessed a rather low turbulence and provided an

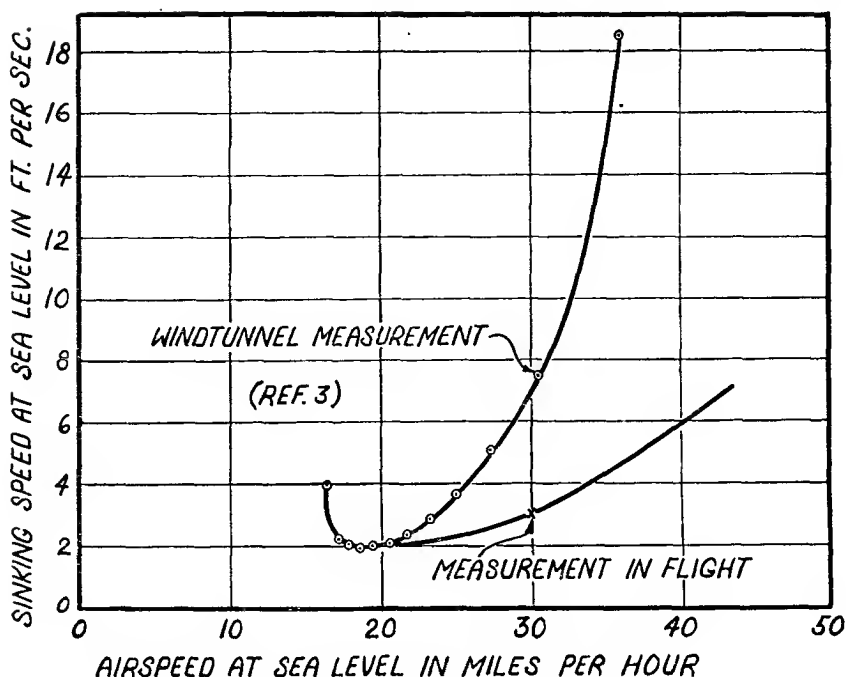


FIGURE 1.—Velocity polar of a laughing gull.

environment quite representative of that which one might find in the atmosphere. On comparing the sinking speed obtained from the wind-tunnel measurements, one sees that the sinking speed of the clay model is a little more than double that of the actual bird measured in flight at the speed of 30 miles per hour. The flight measurement consisted of a very simple comparison of the flight of the gull, while soaring on a ridge on Long Island, relative to that of a sailplane. The pilot in the sailplane was able to adjust his speed to follow the bird exactly, and at this particular forward speed, the bird and the sailplane flew back and forth on a ridge for about 2 hours, neither outclimbing the other.

This is proof that their sinking speeds at this forward speed were identical. It is just this concept of comparison flying which I will discuss in connection with some measurements of the black buzzard. The technique was developed to a higher state and used to get the complete measurement of the drag of a bird over the speed range of its flight in the gliding phase.

However, in order to determine the nature of the aerodynamics of birds in terms of the known parameters used in aeronautics, we must refer the drag to a nondimensional drag coefficient C_D :

$$C_D = \frac{D}{\frac{1}{2} \rho V^2 S'}$$

where D is the drag in force units, ρ is the air density, V is the velocity of flight, and S is the wing area, including that intercepted by the body.

In a similar matter we define the lift coefficient C_L ,

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 S}$$

where L is the lift in force units. If, now, the velocity polar of figure 1 is transformed into a curve of C_L^2 versus C_D , we obtain figure 2. The reason for plotting against the square of the lift coefficient is quite evident when one sees that the induced drag coefficient—that is, the drag due to lift—is a function of the square of the lift coefficient:

$$C_{Di} = \frac{C_L^2}{AR_e}$$

where AR_e is the effective aspect ratio:

$$AR_e = \frac{b^2}{S} e,$$

b being the span and e the span efficiency factor.

What one sees from the linearized drag polar of figure 2 is that the

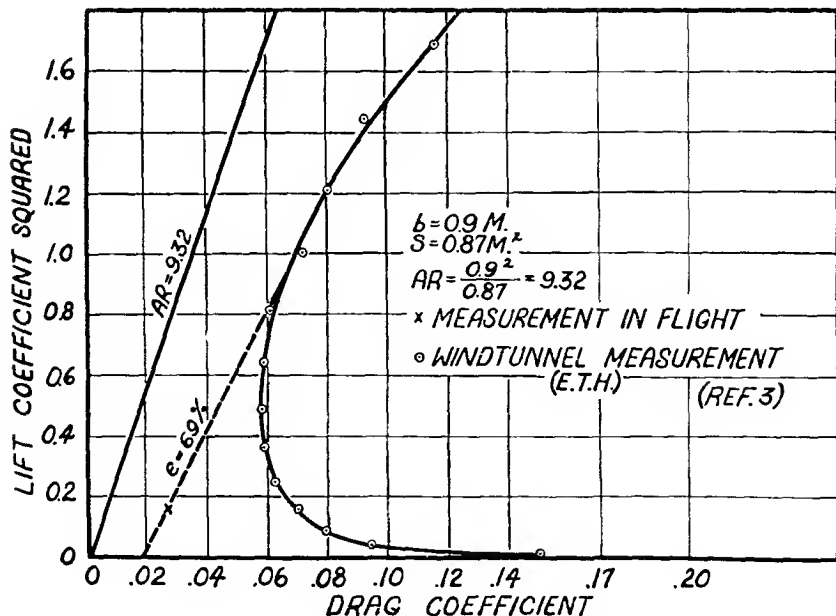


FIGURE 2.—Linearized drag polar of a laughing gull.

flight-measured point lies on an extension of the linear portion of the wind-tunnel measurements. This indicates that the wind-tunnel results must be in error below a lift coefficient equal to 0.8.

Obviously, the clay model was not representative of a feathered bird in flight. In fact, it is doubtful that even a feathered model could accurately duplicate the aerodynamic properties ascribable to the elasticity and mobility of the feathers on a live bird.

However, one can admire the finesse with which nature has designed her flying machines in observing the neat intersection of wing and body in figure 3, which shows a drawing of the laughing gull, taken from Feldmann's paper. In this drawing, the very pointed tips of the soaring birds of the sea are conspicuous. In figure 4 the distinctly different tips of soaring land birds are shown. The question then arises, What is the function of this pointed tip as contrasted with the slotted wingtip of soaring land birds?

It has been suggested that since soaring land birds must land and take off from trees, a large span would be a handicap. Therefore, the slotted wingtip serves to diffuse the vortex flow at the tip, permitting the soaring land bird to attain good performance in spite of limited aspect ratio. The sea bird on the other hand is not limited by its environment with respect to aspect ratio.

However, an analytic investigation by Newman [4] disputes the premise that the slotted tip can reduce the induced drag over that of a solid tip. We are then left without a logical explanation for the slotted tip of soaring land birds. Wind-tunnel tests with smoke streams and a live bird trained to fly in a tunnel could add to our knowledge of this important distinction between soaring land birds and soaring sea birds.

In order to duplicate this complicated model, the live bird, one might freeze a bird and then test it in a wind tunnel. This was done at the Washington Naval Shipyard wind tunnel some years ago, but again we have the criticism that a change occurs in the elasticity of the support of the feathers, as well as in the feathers themselves, in the process of freezing the bird. Another criticism of the frozen-bird technique lies in the fact that the bird uses its wing muscles even in gliding flight as a means of control. This is necessary, since the bird possesses little or no inherent aerodynamic stability except possibly along the body axis in roll. In yaw and, to a lesser extent, in pitch, the bird with fixed geometry appears to have neutral or negative stability. In other words, the flight of a bird is stabilized by minute involuntary control deflections. This is similar to the process of walking in man, in his erect posture.

Another feature of the bird's aerodynamics is the porosity of the feathers. Whether or not this feature plays an important role in the aerodynamics of the bird has not yet been established. Victor Loughheed is reported to have measured the porosity of the bird's feathers, finding the porosity 10 times greater in the downward direction than in the direction up through the wing feathers.

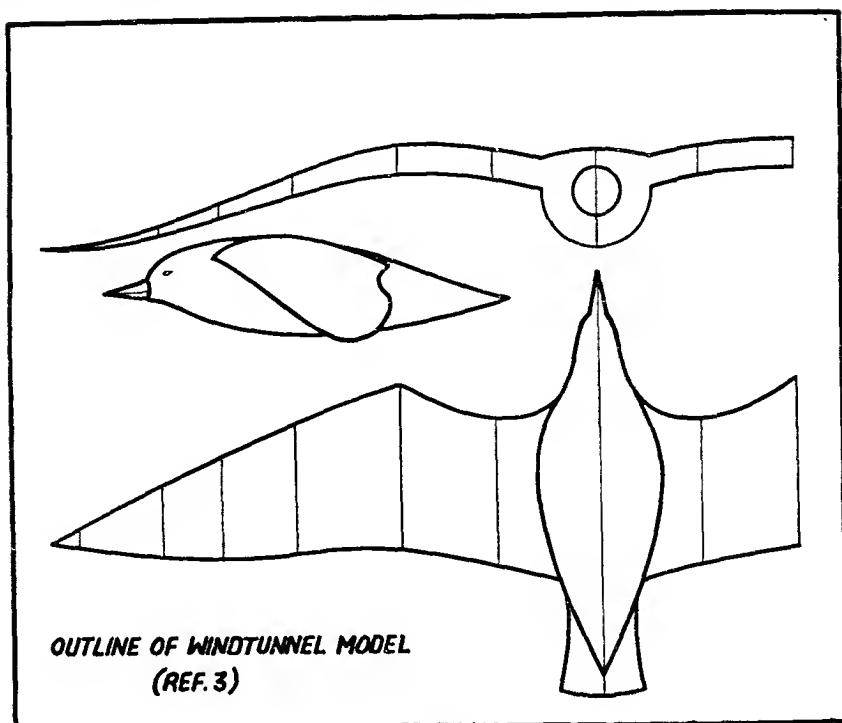


FIGURE 3.—Three views of a laughing gull.

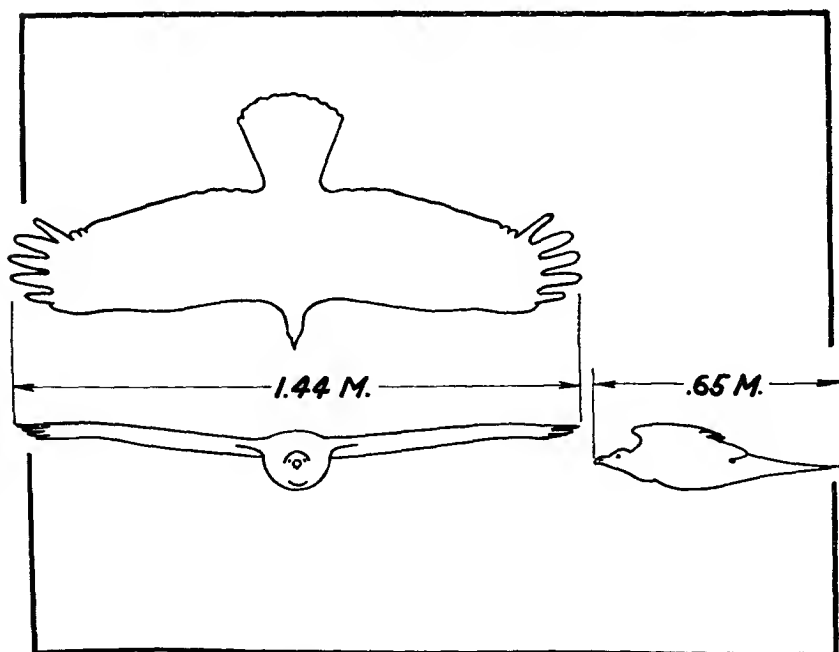


FIGURE 4.—Three views of the black buzzard.

In some birds, in addition to the usual features of the feathers—flexibility, mobility, and porosity—there is also a toothed leading edge. This is true particularly in owls, which must fly silently and stealthily upon their prey in the field. Graham [5] believes that this toothed leading edge reduces the velocity of the flow over the wing. This may be so, but if there is too much loss of velocity in the flow near the leading edge, a wing with a toothed leading edge will not develop as high a lift as one without this edge. This means that the bird with a toothed leading edge to its wing would have to fly faster than one with a smooth-edged wing. Thus, the noise would not be essentially reduced. Yet the owl does fly silently.

Perhaps we might speculate on the function of the toothed leading edge by drawing on an analogy. If a piece of wire of cylindrical form about 3 millimeters in diameter and 1 meter long is swung through the air in a rotating motion similar to that of a propeller, a distinct tone similar to that of a singing telephone wire is emitted. Now, if instead of a single cylindrical wire, two wires of 1.5-millimeter diameter are twisted together in a tight spiral and then spun, the noise level is much lower in intensity and in frequency. In fact, only the free end emits a noise.

From this experiment we might say that the toothed leading edge behaves in the same way that the twisted wire does—that is, in a manner to reduce the vortex noise emitted by the flow leaving the wing. However, remember that this is merely a hypothesis and not absolute proof of the function of the toothed leading edge of the wings of owls.

Since the bird possesses little or no inherent stability in pitch, the question of the function of the tail arises. In general, the tail is used as a landing aid similar to the flap on an airplane. Photographs show clearly that the tail of most birds fans out to increase the lifting area just before touchdown and is folded during gliding flight.

At the same time, during the landing, it will be seen that the alula or false feather, representing the thumb of our hand, opens in order to increase the lifting power of the wing. This same alula is used as a lateral control for initiating rapid turns.

The reader may wish to try a simple experiment which illustrates the function of the alula. If, while driving at about 50 miles per hour, one puts his hand out of a car window with the hand cupped slightly and at a positive angle to the wind, he can, by simply moving his thumb up or down, cause a large change in the lifting force his arm experiences. This is how the bird applies control in roll about his longitudinal body axis.

Having seen, in figure 1, that wind-tunnel tests of bird flight are fraught with possible large errors, we are forced to look for new means of determining the aerodynamic properties of bird flight.

From about 1890 to 1900, S. P. Langley, then Secretary of the Smithsonian Institution, attempted to determine the flight characteristics of buzzards in the neighborhood of Washington, D.C., by photographing the birds with two telephoto cameras, arranged stereoscopically. Such a technique would certainly have determined the geometry of the bird while the bird was airborne, but it would not have determined the energy losses, unless a time-lapse method had been used, together with triangulation by double theodolite methods.

In view of the difficulty of studying the flight of wild birds from the ground, George Carter and I, in 1945, started an experiment in which a young wild buzzard was to be trained to carry a small recording barograph and anemograph attached to its belly. The bird was trained successfully to do its job and to carry a mockup of the recording instrument, which was to weigh 30 grams and have dimensions of 2 by 3 by 5 centimeters. However, before the actual measurements could be made, the bird died of an intestinal stoppage. Our success in training this bird was due to the skill and understanding of George Carter.

Had this experiment been successful, it would have yielded the sinking speed as a function of airspeed—that is, the speed polar, similar to that in figure 1. But for a soaring land bird we would need to observe the mode in which the bird is flying in order to delineate the function of the variable geometry of the slotted wing tip.

Furthermore, the success achieved in training this one bird by Carter clearly supports his contention that it would be possible to train live birds to fly in a wind tunnel whose axis could be inclined to the horizon. Thus, one could force the bird to fly at different gliding angles and at different air speeds, simply by inclining the tunnel and varying the air speed so that the bird would remain motionless in the throat of the tunnel. With this method, one could delineate the function of the slotted wingtip as well as derive drag polars for various changes in geometry which the bird would be compelled to make in order to stay in the tunnel.

COMPARISON-FLIGHT STUDIES

Since the technique of using trained birds was so dependent on the training of the birds and so time consuming, the comparison method of flying with birds in a sailplane was developed in 1949 [6] as a refinement of the simple one-point comparison test made on the laughing gull, as represented in figure 1.

In the comparison method for determining the speed polar and consequently the drag polar of a bird in free and natural flight, a sailplane of low sinking speed and low forward speed capability is needed. In addition, the sailplane must be highly maneuverable, since the pilot must follow birds that can turn with extreme rapidity.

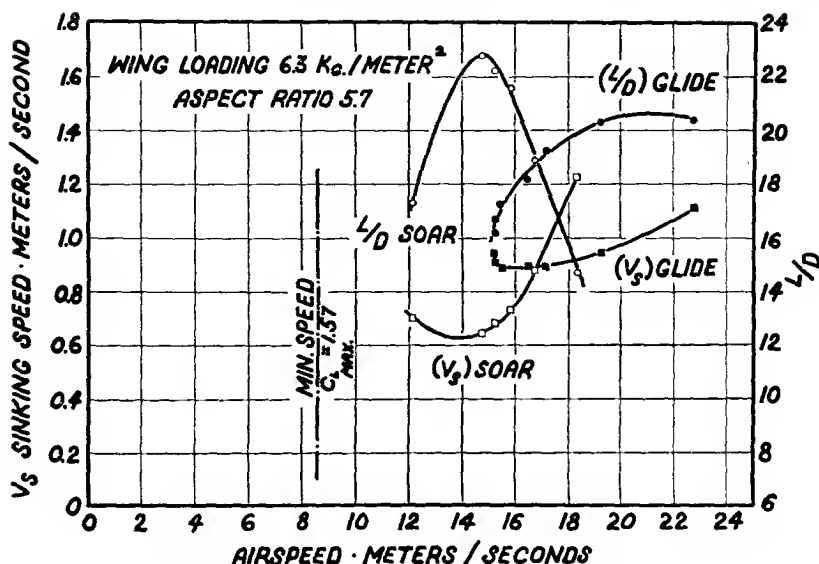


FIGURE 5.—Velocity polar and glide ratio of a black buzzard.

Plate 2 shows a sailplane rigged for bird-flight research. A small radio transmitter and receiver are carried, for transmitting data to a data recorder on the ground. The telephoto camera on the nose of the sailplane is used to record the geometry of the bird. However, the results obtained with this camera were not helpful, because it was not possible to determine the orientation of the tip feathers from the nonstereoscopic photographs.

In making these measurements, the sailplane was launched either by a ground tow behind an automobile on a long runway or by an airplane tow. When the sailplane reached an altitude where upcurrents were strong enough to support it, the pilot would release and soar in a good upcurrent. Ground observers would scan the skies for buzzards, and when one was found, would direct the pilot to the buzzard by radio. When the pilot located the bird he would descend to the altitude of the bird and then follow it, staying no more than 5 to 10 meters behind it. At 30-second intervals, the pilot would report the airspeed at which he and the bird were flying and the altitude of the bird above the horizon, measured in wing spans.

Subsequently plots of the altitude of the bird against time yielded, from the slope of this plot, the difference in sinking speed between the bird and the sailplane. Then, by measuring carefully the sinking speed of the sailplane in the still air of the morning at various airspeeds, one can obtain the speed polar of the sailplane. Adding to this polar the differences in sinking speed between the bird and the sailplane, we arrive at the speed polar of the bird (fig. 5).

In this illustration, the two modes of gliding flight yield two different speed polars for the bird. In the soaring mode the bird flies with open tip slots, while in the gliding mode it flies usually on a long descent at relatively high speeds, with tip slots closed. Also, in the latter mode the bird introduces an M-shaped sweepback, whereas in the soaring mode there is a pronounced forward sweep of the wing. Figure 4 shows the black buzzard (*Coragyps atratus*) in its soaring mode.

Returning to figure 5, we see that at a speed of 17 meters per second the speed polars cross. Above this speed the bird chooses the gliding phase, for when the bird is gliding its sinking speed is considerably lower than it is with the tip feathers opened. Below 17 meters per second the bird finds that it can reduce its sinking speed by opening the tip slots, and can thereby increase its glide ratio (L/D). The glide-ratio curves represent the distance the bird can fly for each unit loss of altitude. In other words, the black buzzard is capable of gliding 23 miles in still air from an altitude of 1 mile at its best glide ratio. This remarkable feat is possible at a relatively slow forward speed of 15 meters per second with tip slots open.

An interesting biophysical constant can be derived from the velocity polar of figure 5. If we wish to determine the minimum power required for the bird to maintain level flight, we take the product of the minimum sinking speed of 0.62 meter per second and the weight of the bird. This yields the rate of loss of potential energy which must be compensated by muscle power for the black buzzard in level flapping flight. The minimum power required to maintain level flight is 0.019 horsepower. For this bird, which weighs 2.3 kilograms, this results in a power loading of 122 kilograms per horsepower. A rough value for the capability of muscles to put out continuous power is 1 horsepower for 50 kilograms of muscle.

The value of 122 kilograms per horsepower then implies that flight muscles must constitute 42 percent of the bird's weight. If, then, flapping muscles do not constitute at least 42 percent of the black buzzard's weight, we can conclude that this buzzard could not maintain continuous level flight without help either from upcurrents or from dynamic soaring, in which energy is extracted from the fluctuations in the wind.

In order to compare the aforementioned free-flight method for determining the aerodynamics of a bird in gliding flight with wind-tunnel measurements, the data of figure 5 have been transformed into a linearized drag polar (fig. 6). In this illustration are shown the drag polars of the black buzzard in the two modes of gliding flight and wind-tunnel data for the laughing gull, the cheel (pariah kite), and the Alsatian swift. The same conclusion that was drawn from

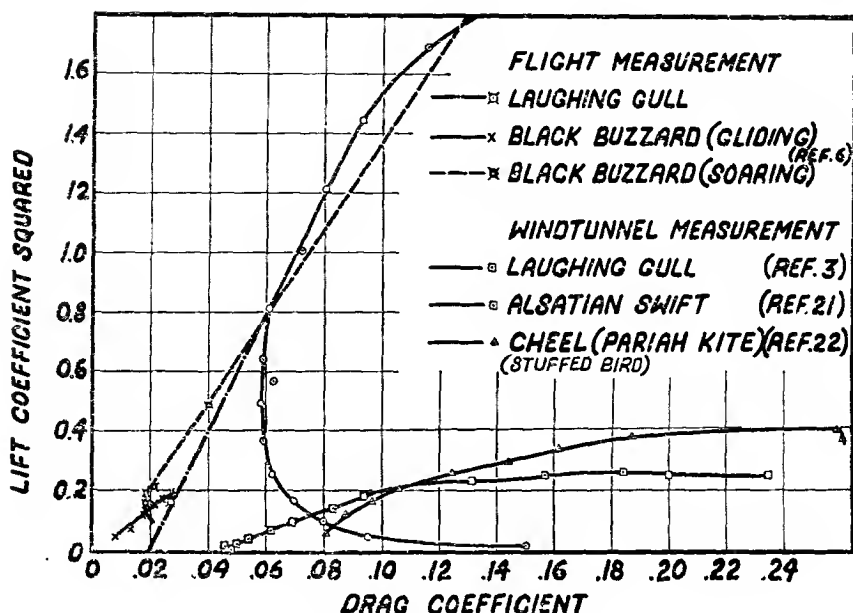


FIGURE 6.—Linearized drag polar of the black buzzard, laughing gull, Alsatian swift, and cheel.

the single laughing gull measurement is borne out by the complete polars of the black buzzard—namely, wind-tunnel measurements of models of birds cannot yield valid information concerning the aerodynamic properties of birds in natural flight. For this reason, progress in understanding the more difficult phases of flapping flight will only be possible when theory can be supported by flight measurements made under natural conditions. In general, the measurements made in wind tunnels tend to ascribe to the bird much higher energy losses than it actually experiences. For this reason, any biophysical conclusions would lead to absurdities if they are based on wind-tunnel measurements made on model or stuffed birds.

However, the comparison-flight method is subject to some criticism at the present state of the art. Since the measurements with wild birds had to be made in the middle of the day when birds were soaring—that is, in a turbulent environment—one cannot absolutely say that the black buzzard possessed the very low drag coefficient which was measured. We say that either it possesses this low drag coefficient or else it must be utilizing a source of energy which the sailplane was not. The only possible means of extracting such energy from the environment lies in dynamic soaring. However, we do have rather positive evidence that the lowest measured drag values are valid for the high-speed points on the speed polars of figure 5, since they were obtained near sunset when the air was quite smooth, during a glide to roost of a black buzzard.

Nevertheless, there cannot but be some doubt about the validity of data taken in turbulent air. For this reason, making a measurement during the early hours of the morning when the air is very still suggests itself. For this test, several wild captured buzzards would be carried aloft in a two-seater sailplane. On tow, behind the same towplane, would be the measuring sailplane, of light, maneuverable design, fitted with radio communication equipment. After the two sailplanes reach an altitude of 1,500 meters, they will be released from the towplane, which will descend to the airport. The bird-carrying two-seater will move ahead of the measuring sailplane, headed toward the airport where the birds have been cooped. On a signal from the measuring sailplane, the bird handler will release a bird from the two-seater by dropping it out in an open-ended bag, to which is attached a line. At the end of the line, the bird will fall out of the bag, head first, and will start gliding toward its coop. Whether every bird will cooperate in this manner is yet to be determined. However, if the birds merely glide in any direction, useful data can be obtained, for the measuring sailplane is capable of landing in any small field and can be disassembled for return to its base by trailer [6a].

During the glide of the bird, the measuring sailplane will record data in the manner ascribed for the comparison-flight method.

The precision of this method should be much greater, for, in this case, both the bird and the sailplane will be flying in smooth air, that in which the sailplane has been calibrated.

The results of these measurements in still air should either confirm the measurements given in figure 5 or perhaps, under certain flight conditions, especially at the lower speeds with the bird's slotted wing-tips open, reveal a disparity. If the difference is significant and if the sinking speed measurements made in turbulent air are lower than those made in still air, then we must look to the mechanism of dynamic soaring for an explanation. As a matter of fact, the investigation of the nature of this energy extraction will yield valuable information on the little-known science of dynamic soaring, of which some aspects are discussed below.

BIRD AND AIRPLANE

Up to now, all our comparisons of bird aerodynamics have been "within the family." The question naturally arises, How good is the bird compared with modern aircraft? Obviously, trying to compare a bird cruising at 30 to 60 miles per hour with a supersonic airplane would be absurd. Even if we compare the bird with some of our subsonic airplanes, we still have the problem of scale and speed differences. Fortunately, we can rely on the well-known Reynolds number

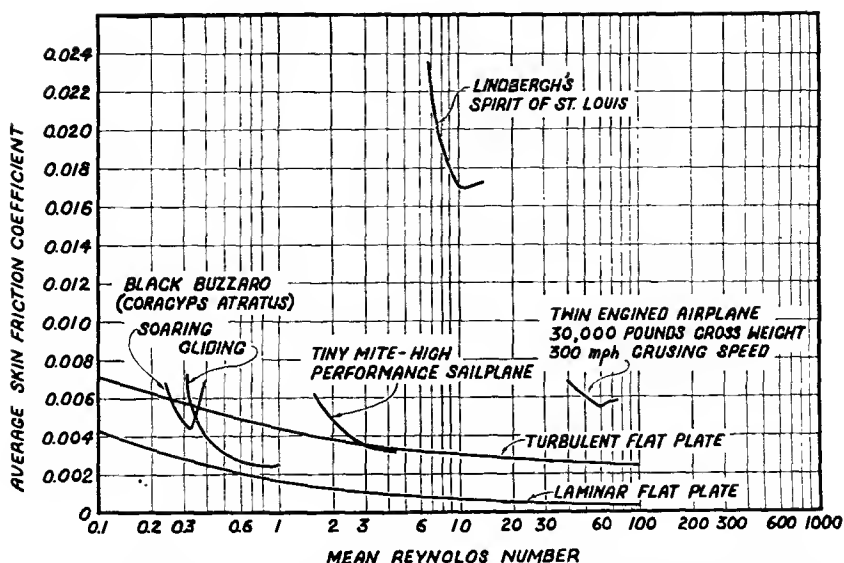


FIGURE 7.—Skin friction curves plotted against mean Reynolds number for the black buzzard, a high-performance sailplane, and a high-performance twin-engine airplane.

as a means for eliminating the objection that we are comparing vehicles in different domains of the viscous-flow regime.

In figure 7, the drag polar of the black buzzard in its two modes, gliding and soaring, has been transformed into a plot of average skin-friction drag coefficient versus Reynolds number. On the same plot are shown the Blasius curve for pure laminar flow over a flat plate and the Von Karman curve for turbulent flow over a flat plate. These two curves provide us a standard over the rather large scale and speed domain covered, from birds to large airplanes.

It should be mentioned that the data for the airplane shown were also obtained in gliding flight, with propellers feathered after the plane had climbed to altitude on its engines. When we look at figure 7 we find that the black buzzard's skin-friction coefficient is only 30 percent higher than that of the laminar plate, whereas our best man-made flying machine, a sailplane, possesses a skin-friction coefficient 330 percent higher than the laminar flat plate flow. And our best-measured airplane has the poorest showing, having 29 times greater skin friction than the laminar flat plate.

From this curve we can conclude that the many generations of selective breeding have resulted in a flying machine, the bird, which still gives man a goal toward which to strive.

Furthermore, the fact that the high-speed end of the curve of skin friction for the bird came from data points taken in calm air gives some validity to a speculation that the bird must, through the porosity

of its feathers, exercise some type of boundary layer control—that is, that there must be some automatic fluid mechanical process in the bird's makeup by which a good portion of the flow over the bird's surface is kept laminar. The difference in porosity measured by Victor Loughheed may be the key to this process.

In fact, on the basis of this speculation, I was inspired to attempt to duplicate the boundary layer control which I suspected the birds were achieving. By making many small holes in a section of a sailplane wing and sucking the boundary layer into the wing with a fan, I was able to measure drag reductions of the order of 50 percent when even the power required for the suction fan was considered to be a loss [7]. Later on, it was also discovered on this sailplane that this same suction could increase the lifting power of the wing. We may thus further speculate that the bird may be utilizing boundary layer control, both for high lift and for low drag.

Recently, a very fascinating discovery was reported by Kramer [8]—that there exists an automatic boundary layer control in the skin of the porpoise. Examination of the skin of the porpoise disclosed that the porpoise is completely covered with a hydraulic skin one-sixteenth inch thick that is elastic and ducted. Kramer was able to duplicate this natural boundary layer control device by selecting a rubber skin of suitable stiffness and by introducing a damping fluid behind the skin. The stiffness was controlled by small rubber stubs. Between the stubs was the damping fluid.

But it is conceivable that Nature has solved this problem for birds in a manner that is not analogous to the solution for the porpoise.

The problem of trimming an aircraft for various speeds is particularly vexing on flying-wing aircraft. Since all birds are essentially flying-wing aircraft, it is possible that we can learn a trick or two from the way birds apply trimming moments for various flight conditions. We know that the bird's wing is in general fairly highly cambered. Therefore, we can expect large pitching moments. In order to achieve stable flight, these pitching moments must be balanced by aerodynamic moments developed by the tail of a conventional airplane or by twisting and deflected elevators at the wing tips on a swept flying wing.

Let us look at a comparison of a flying-wing sailplane and the black buzzard (fig. 8). Instead of plotting C_L^2 versus C_D , as we did before for the linearized polar, we have plotted C_L^2/AR versus C_D , which is in actuality a plot of the theoretical induced-drag coefficient versus total-drag coefficient C_D . The purpose in doing this was to be able to derive some information on the induced drag from aircraft of widely different aspect ratios—namely, 5.7 for the bird and 21.8 for the sailplane.

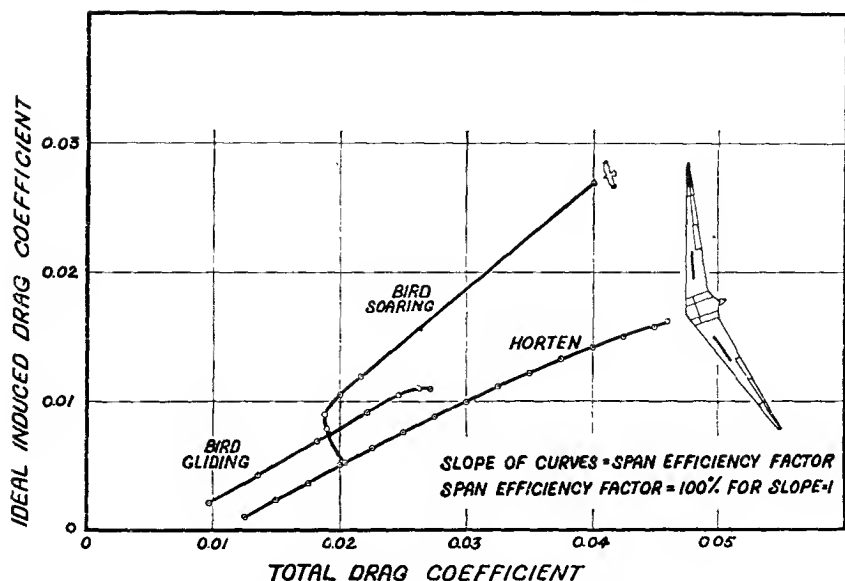


FIGURE 8.—Comparison of span efficiency factors of the black buzzard and the Horten IV tailless sailplane.

It is immediately apparent that the slope of the curve for the buzzard is much steeper than that for the sailplane. This means that if the two had the same aspect ratio, the bird would outperform the sailplane, especially at the high-lift coefficients used in soaring. In studying the reason for the high induced drag of the Horten IV flying-wing sailplane, we found that the elevators at the trailing edge of the wing caused a severe induced drag, owing to the change in the spanwise lift distribution necessary for trimming the sailplane at high angles of attack.

The question is, then, How does the bird accomplish this trimming without suffering the resultant induced drag rise? Figure 9, taken from Hankin [9], shows the plan form of a buzzard (*Otogyps calvus*) in various flight modes. At low speeds, the wings are swept forward. In other words, the center of pressure of the wing is moved forward of the center of gravity of the bird. As a result, an upward pitching moment is developed which counterbalances the nose down-pitching moment of the highly cambered wing.

Whether the trimming by means of forward and backward sweep results in a stable configuration in pitch cannot be determined without a knowledge of the camber and the angle of attack distribution of the bird's wing. However, the bird is capable of correcting for instability by means of intuitive sensing and associated reflexes.

The process of trimming to different speeds is clearly seen from figure 9. At very high speeds, the tips are swept back by bending

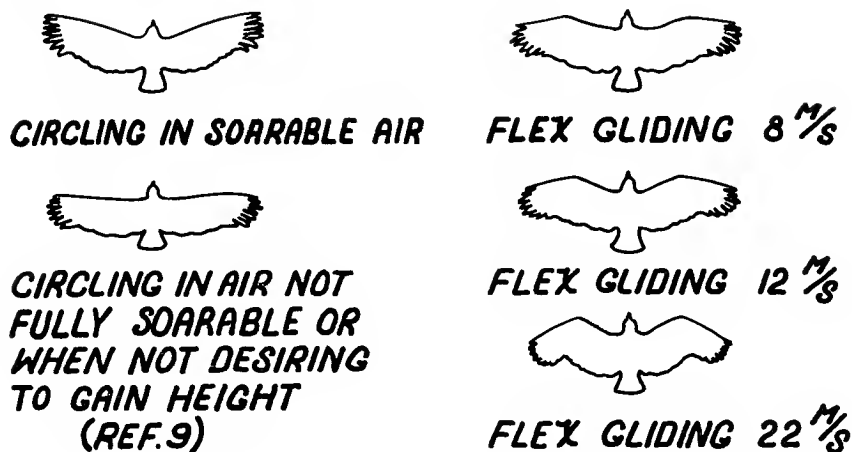


FIGURE 9.—Wing configurations at various flying speeds for *Otogyps calvus*.

the elbow of the wing. This tends to move the center of pressure of the wing farther back, a nose down-pitching moment and trimming for higher speeds thus being achieved.

The foregoing explanation of the control of a bird in pitch is admittedly sketchy. It would, however, be entirely possible to carry out experiments on the control and stability of a bird which had been trained to fly in a tunnel that could be inclined with the horizon so as to force the bird to fly at different glide ratios and speeds. By adding weight to the bird ahead of, or behind, its center of gravity, it would be possible to introduce pitching moments for which the bird would have to compensate with sweep of the wings.

SOARING

So far we have discussed only the aerodynamics of the bird in gliding flight and the bird's stability. Now we will consider the process of gaining energy from the atmosphere—namely, soaring. Static soaring is accomplished by flying in an upward-moving air-mass having a higher vertical velocity than the bird's minimum sinking speed. By staying within the confines of such upcurrents, the bird will gain altitude.

One common cause of upcurrents is orographic lifting as the wind passes over a ridge. Birds are capable of soaring on declivities of very small dimensions. However, they also soar on mountainsides, the best example being the soaring of hawks on Hawk Mountain in Pennsylvania.

With a sailplane fitted with a sensitive instrument measuring the rate of climb, a pilot is able to duplicate the bird's feat of soaring on a ridge. In fact, often a sailplane pilot merely needs to follow the bird in order to find the best lift.

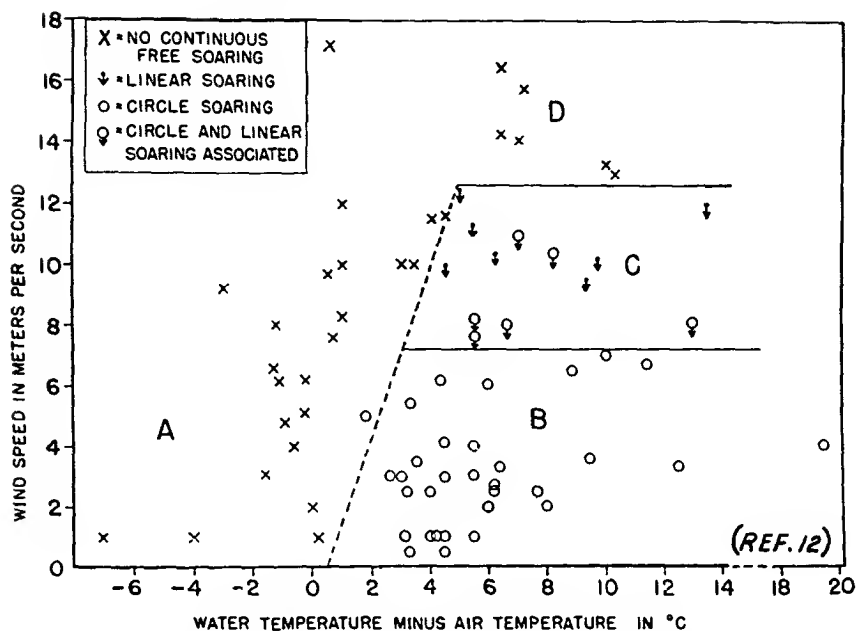


FIGURE 10.—Modes of soaring of herring gulls, based on temperature increment and wing speed.

Just how the bird measures the vertical velocity and just how it determines which way to turn in order to stay in the upcurrent are questions which we cannot presently answer.

Another source of energy for soaring is that provided by thermal upcurrents. These exist both in hilly and in flat country. A very thorough exposition of the nature of birds soaring on thermal upcurrents is given by Huffaker [10]. Not only did Huffaker in 1897 clearly describe the bird's thermal soaring but he also indicated that there is good reason to believe that birds have some means for detecting thermal upcurrents at a distance, for they often head directly for a given area and begin circling. They inevitably gain altitude.

Some years ago I speculated that the bird must measure in some way the temperature gradient in the horizontal plane and that from this gradient it is able to determine the direction toward the warm upcurrent core. An attempt to do this in a sailplane merely proved that we know too little about the nature of thermal upcurrents to be able to devise instruments for prospecting for the thermal upcurrents [11].

Another form of upcurrent, still a thermal upcurrent but over water instead of land, was beautifully studied by Woodcock [12], using herring gulls as his indicators of the nature of the upcurrent. In figure 10 is shown a plot taken from Woodcock's paper, which delineates the type of thermal upcurrent, a columnar or cylindrical vortex with axis horizontal. This research is a clear example of the

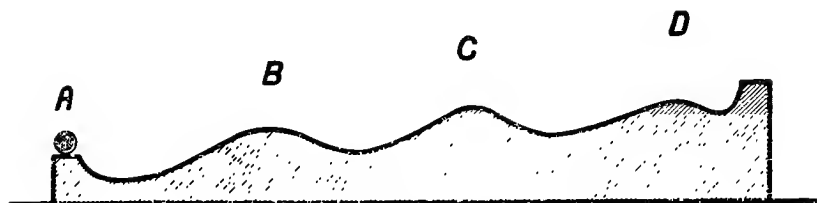


FIGURE 11.—Bazin's dynamic soaring analogy.

careful observation and analysis which should be applied to more of the problems of bird flight.

The third source of energy for soaring is that which Lord Rayleigh described as flight through air which possesses velocity fluctuations. On the basis of this thesis, S. P. Langley [13] made a study of the energy available in the wind. However, the actual mechanism of dynamic soaring was not clearly disclosed until Klemperer [14] published his paper. Reduced to its simplest form, dynamic soaring is merely correcting for the turbulence in the airmass in such a way that potential energy is gained. Klemperer's contribution points a clear path toward the duplication of this process by man. So far, only certain birds are known to utilize dynamic soaring—in particular, the albatross.

The strict condition to be fulfilled, as Klemperer points out, is that the sailplane or bird must be immobile against pitching under the influence of gusts. Under this condition, an upwardly directed gust results in increasing the angle of attack, thereby lifting the bird or sailplane. A gust having a horizontal component of velocity will result in an increase in effective airspeed, thereby increasing the lift. In practice, this process might be accomplished on a sailplane by using modern gyroscopes and servo controls.

A simple model of an analogy for dynamic soaring is shown in figure 11. By oscillating the model along its axis with a higher acceleration in the forward direction than in the reverse, the marble is made to climb to the last stage of the model. Interestingly, Bazin [15] and Lanchester [16] invented this analogy independently.

Idrac [17], in his carefully documented study of the soaring flight of birds, described a second type of dynamic soaring practiced by the albatross. This bird flies an elliptic path, one vortex of which is in an area of high-velocity flow and the other near the water's surface, in wind of relatively low velocity. In other words, this bird utilizes the energy in the boundary layer of the earth.

The last phase of soaring has yet to be accomplished by man, although many have tried it. The Russians have recently (1956) flown a sailplane with elastically supported flapping wings capable of being "tuned" to the turbulence. No significant gains were reported,



Artist's conception of Leonardo da Vinci's flying machine in flight. Note that da Vinci, knowing human anatomy as he did, at least tried to harness the powerful thigh muscles, whereas many other experimenters used only the arm muscles. (From a painting by Robert Riggs, courtesy of International Business Machines Corp.)



Sailplane for research on bird flight.

nor was any demonstration made to indicate such gains. Perhaps we need to study the dynamic soaring of birds in more detail before we can hope to succeed.

The last and least understood phase of bird flight is that of flapping. Aerodynamic theories for unsteady lifting of wings have been developed, but still there is much to be learned from the complex flapping motion of flexible wings, having slots which can open or close in various phases of the flapping motion.

Insofar as the actual motions of flapping flight are concerned, by far the best description is contained in the documentary work of Marey [18], who used a time-lapse photographic technique to define the flapping motion of the wings of birds. His three-dimensional models showing the flapping sequence are works of art. However, his studies, while of historic interest, contribute little to an exact understanding of the physical mechanism of bird propulsion by flapping.

Of the more recent works in the field of flapping flight, there is the work of Küchemann and Weber [19]. In a chapter of their book entitled "Aerodynamic Propulsion in Nature," the authors make a clear comparison of the oscillating wing and the propeller.

At the very low speeds of landing and takeoff of birds, the propulsive efficiency of a propeller would be rather low. However, if the entire wingspan is used to accelerate a large mass of air above it, thereby achieving a change in momentum with a relatively small velocity increment applied to the large mass, the efficiency remains quite high. In fact, if the flapping wing as a propulsor could be designed for airplanes which are to take off and land in short distances, it would provide a very important contribution in its high propulsive efficiency at low speeds.

The actual power required for flapping flight and the propulsive efficiency of the bird have not yet been measured. This is a challenging problem, but one fraught with experimental difficulties. However, with modern miniaturized instruments and telemetering, it should be possible to gain some insight into this problem.

From the zoological side, there has been a very thorough study made of the musculature of buzzards by Fisher [20]. However, the question of determining which muscle plays a part in delivering power to the wing has not been satisfactorily answered. If it were, we would be able to determine the power output which these muscles can provide for flapping flight.

From the standpoint of the biophysics of bird flight, we probably can sum up the state of our present knowledge by saying that we know very little. A few measurements have been made which were quite revealing when the bird was compared to man's creation, the

airplane. However, there are still many facets which challenge both the experimentalist and the theorist in this field of natural flight. It is my hope that some of these challenges will be accepted by biologists, physicists, engineers, and mathematicians.

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Animal Societies, From Slime Molds to Man

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THOUGH the great majority of animals as adults lead solitary lives, except at the mating seasons, there are some that live in groups of interdependent individuals. Among the lower invertebrates the individuals of such a group are usually anatomically connected, and these species are termed "colonial" by zoologists. On the other hand, there are true social organizations of free individuals, as with some of the insects and man, which are known as "societies." The two terms, however, are more commonly used interchangeably. Then there are many animals that associate in herds, flocks, schools, and swarms. Such species may be said to be sociable, but they are merely gregarious. With the truly social animals there is always something that acts as a bond for unifying the members by making them mutually dependent on one another. The nature of the bond, however, may be quite different in different societies.

THE SLIME MOLDS

A slime mold, or slime fungus, in its usual form would never be suspected of being a colonial or social animal. It is a flat mass of protoplasm known as a plasmodium, generally a few centimeters or inches in diameter, containing numerous nuclei but no cell walls. It lives in damp places on decaying leaves or logs, over which it slowly moves by a flowing motion or by sending out pseudopods, picking up food particles as it goes. In the plasmodium stage the creature is an animal that might be likened to a giant amoeba. In its reproductive stage it becomes plantlike. Zoologists therefore call its kind Mycetozoa, and the botanists call it Myxomycetes. In the reproductive stage, spore-bearing stalks like the sporangia of a fungus grow out from the back of the plasmodium. The spores when ripe are scattered by the wind; those falling on water become minute flagellate protozoa, each of which multiplies rapidly by division. Then these simple one-

celled animals unite in pairs like spermatozoa and eggs, forming zygotes.

Now comes the remarkable part of the history of these strange creatures. The zygotes are essentially living protozoons. Where many are assembled on the water, as they meet one another they unite in large numbers and form a new plasmodium. The result is not an aggregate of cells, but a complete fusion and blending of the zygotes into a protoplasmic mass, in which only the nuclei remain distinct. Nothing like this occurs elsewhere in the whole realm of nature. No outside force brings the zygotes together; it is as if these tiny bits of protoplasm have an instinct to unite, or is it merely chemical attraction? Wells, Huxley, and Wells (1934) liken the plasmodium to the whole human population of a town fused into a great mass of living substance, which then creeps about as a single creature. This would be socialism carried too far for its strongest advocates. Here, on the very lowest level of life, we find the most complete surrender of the individual to the community.

VOLVOX

Among the Protozoa there is an interesting fresh-water colonial form named *Volvox*. It consists of hundreds or thousands of minute biflagellate one-celled individuals, or zooids (zō-oids), set closely on the periphery of a gelatinous sphere, as much as 2 millimeters in diameter. The vibratile threadlike flagella of the zooids project from the surface and cause the sphere to move through the water. Very surprisingly, the action of the flagella is so coordinated that the colony always moves with one pole forward. *Volvox* reproduces both asexually and sexually. In the first form, a zooid divides to form a miniature colony inside the parent, which then breaks out through the wall. In sexual reproduction some zooids enlarge to become the equivalent of eggs, and others divide to form spermatozoa. The two forms of gametes then unite in pairs as zygotes, which by repeated division form new colonies.

The zooids of the *Volvox* colony are perfect protozoan individuals, and yet they never know an independent life. They are but little differentiated, except that the anterior zooids are smaller and non-reproductive. Since the body of a metazoic animal may be regarded as a society of differentiated cells, it has been suggested that the *Volvox* colony shows how the many-celled animals may have been derived from Protozoa, and the globular *Volvox* colony has even been likened to the blastula stage of a metazoon. However, it is not contended that *Volvox* is ancestral; it is simply an imitation blastula. As a motile colony of closely adherent individuals it is unique.

THE COELENTERATA

The coelenterates are many-celled aquatic animals, mostly marine, that occur in two principal forms, one typified by the hydras and sea anemones, the other by the jellyfish, or medusae. The two, however, are merely versions of one type of structure, the polyp. The simplest example of the polyp form is the fresh-water *Hydra*, which is a small, double-walled cylindrical bag attached by one end to a support, open at the other by the mouth, which is surrounded by a circle of tentacles. The inner cavity is the stomach. The jellyfish is a polyp flattened lengthwise into the form of a bowl or umbrella, which floats upside down in the water. The mouth is on a central projection of the undersurface; the tentacles hang from the margin.

Hydra propagates itself by lateral branches that assume the parent structure and then break off as new hydras. Other related forms also produce new individuals by branching, but they remain attached to the parent stem. There results therefore a branched, plantlike colony of polyps, which never occur as free individuals. A well-known example of this type of colonial coelenterate is the genus *Obelia*. It grows in the ocean as masses of fine branching threads attached by root processes to shells, stones, and piers along the shore. Most of the polyps are feeding members of the colony; their stomachs are all connected through the branches and the main stem. We have here therefore a colony of individuals interdependent by the possession of a common stomach.

From the lower part of the *Obelia* stem are produced branches that do not take the form of polyps. They are simple shafts with enlarged ends, each enclosed in a transparent sheath. Along the shaft are formed buds that develop into small medusae, which produce the sexual elements; these unite as eggs and spermatozoa and give rise to simple larvae known as planulae. The larvae become attached at one end to a support and develop into polyps that branch and form new *Obelia* colonies. The *Obelia* colony therefore produces both polypoid and medusoid individuals, and the life of the species alternates between a fixed nonreproductive form, and a free reproductive form that produces the sex elements. In the genus *Bougainvillea* the medusae are produced as individual buds from the stems as are the polyps. The common "jellyfish" are medusae that have dispensed with the colonial polyp stage.

There are various other members of the Coelenterata that form branched colonies. When the stems and branches produce a calcareous skeleton, the colony is known as a coral. Corals, however, occur in at least five coelenterate groups. There may be thousands or perhaps millions of polyps in a single coral colony. The so-called stony corals, or madrepores, are the builders of coral reefs and coral

islands. Most of the coral polyps have the structure of sea anemones, which resemble the hydroid polyps, but differ from them in a number of essential ways.

THE BRYOZOA

The bryozoans are another group of colonial invertebrates, known also as Polyzoa. Most of them are branching colonies attached to supports such as shells, rocks, and piles or other similar things along the seashore. In one genus, *Cristatella*, the colony has a matlike form and freely creeps about. The individuals resemble the polyps of a hydroid colony, each having a circle of tentacles around the mouth. In structure, however, the bryozoans are of a higher type of organization than the coelenterates; they are animals with a coelomic body cavity between the body wall and the alimentary canal. Some species, including the common *Bugula avicularia*, are noted for the fact that most of the zooids are armed each with a small appendage resembling a bird's head, which turns from side to side with active snapping movements of the bill. This appendage, the avicularium, however, is a reduced zooid, showing that a differentiation has taken place among the individuals of the colony.

THE HEMICORDA

Among the prevertebrate animals with a notocord instead of a backbone, some species of the Hemicorda, so named because the notocord is restricted to the anterior part of the body, are colonial, but the members are free individuals. Most of them live in tubes of their own construction formed of a secretion from a lobe on the ventral side of the head. A colony usually consists of groups of tubes more or less cemented together. Each animal is anchored in its tube by a long slender tail with an adhesive disk at the end, but it can leave the tube and creep about on the outer surface.

Of special interest are members of the colonial genus *Cephalodiscus* which, instead of constructing individual tubes, build a common house with a central chamber in which they all live together. Through openings in the wall, however, the animals can crawl out and creep about on the outside. Species of *Cephalodiscus* are small animals living fairly deep in the ocean. Each animal has an oval or elongate body crowned with a group of tentacles, at the base of which is a flattened head lobe on the ventral side. Both the mouth and the anus open anteriorly. Posteriorly the body is prolonged into a long slender taillike stalk with an adhesive disk at the end. A *Cephalodiscus* colony is founded by a single sexually developed animal, which reproduces asexually by budding. The buds, however, develop into free individuals, which together build their common dwelling, an irregular structure with spinelike prolongations.

Here is the first case below the insects in which we find a colony of free individuals with a common home. There is, however, no differentiation of the colony members into castes as with the insects.

THE SOCIAL INSECTS

The insects are noted for their diversity of habits and ways of living. It is not surprising therefore that some of them have adopted the social way of life. W. M. Wheeler (1923) lists 21 families and 3 orders of insects containing species that are social in some degree. The social insects of particular interest, however, are the termites, the ants, and certain species of the wasps and bees. Mention should be made also of the webworms and tent caterpillars, which make those large silken domiciles seen in trees. These are juvenile societies, the members of which hatch from a single batch of eggs, and all cooperate in making the tent. Evidently they are activated by a common instinct. They do not revert to individuality until the time for pupation, when they leave the nest separately and each seeks a place for spinning its cocoon in solitude.

The fundamental principle on which the best organized insect societies are based is the restriction of the reproductive function to one fertilized female, known entomologically as the queen. Though the ants do not always enforce this rule, the supernumerary queens are daughters of the primary queen. A single maternity assures uniformity in the members of the society so long as the queen has the proper hereditary units, or genes. Furthermore, the progeny of the queen, except individuals that are destined to perpetuate the species, is sterilized. The sterile forms thus cannot rear families of their own and create confusion. They are destined to be workers, or in some cases soldiers, and are endowed with instincts that tell them what they are supposed to do and how to do it. The workers can still learn a few things when necessary, but they cannot assert independence of action; all their work must be coordinated for the good of the society. There can be no willful deviation from an instinct.

The insect society is thus not a crowd of associated free individuals. It is a thoroughly organized social system. The queen is the mother of the colony, and her principal physical function is egg laying. However, she is also an autocratic ruler of her progeny, though she gives her orders in the form of transmitted instincts. The differentiation of structure and duties among the members of the insect society results in the caste system, but the insect castes have no relation to the "pecking order" of the barnyard, or to the castes of human societies. The workers are dominant in the insect society. Owing to the automatic suppression of individual freedom, insect societies have little internal trouble or dissension, and no such thing as a criminal ele-

ment. Colonies, however, fight and rob each other just as do nations of *Homo sapiens*.

In describing the behavior of animals, we continually use the term "instinct," though we have no proper definition of the word. When members of a species always do the same thing under the same circumstances, it would seem that their performance results from some built-in neuromuscular mechanism activated by a sensory stimulus. Most instincts, however, involve a number of related acts, which should require a complex ready-to-act system of nerve tracts to appropriate muscles, successively activated by sensory stimuli. Such a system has not been demonstrated by neurological studies, but the inheritance of an instinct is understandable only on the assumption that instinct is a function of an inherited physical mechanism.

Insects unquestionably know how to do nearly all the things they do without learning or former experience. But when we think of a cluster of hive bees building a honeycomb with flakes of wax they pick out of pockets on the undersides of their abdomens, manipulating the wax with their mandibles and constructing perfectly hexagonal cells of two sizes, it is difficult to believe that the bees are provided in advance with neuromuscular mechanisms capable of producing such complex coordinated behavior. On the other hand, it is certain that the workers in a comb-building gang are not guided by reason, since they would not all reason alike and their work would be disordered. We must concede that "instinct" is still a word that needs explaining, though it stands for facts that cannot be denied. While much analytical experimental work has been done on the nature of instinct in vertebrate animals, the "mental" development of an insect is so different from that of a vertebrate, that the nature of instinct in an insect is not to be deduced from that of a rat. Vertebrates are conscious animals; insects give no evidence of having consciousness. Yet it is hard to visualize insects, with all their activities, as mere machines that do not know even that they exist. It is as easy to imagine automobiles driving themselves on a crowded thoroughfare without collisions.

THE TERMITES

The termites are insects that have become too familiar to us because of the damage they do to wooden fenceposts, utility poles, and the wooden parts of our houses. They can be very destructive also to books if they gain access to them, not because they have any taste for literature, but because paper is made of wood. Wood, in fact, is the natural food of termites; its chief constituent, cellulose, they digest by means of cellulose-digesting protozoa that flourish in their stomachs.

Our commonest destructive termites live in the ground, but they are always looking for wood lying on the ground or inserted into it.

On finding it they rapidly excavate the interior with galleries. Thus they may secretly invade the woodwork of a house without being discovered until they have done much damage. In other cases large colonies of termites seem to live contentedly in damp places under logs or discarded boards lying on the ground. In the Tropics some species construct nests above ground built of earth particles cemented with saliva, and such nests may reach a height of 20 feet or more. The habits of termites, however, are so various that it is impossible to give in brief a general description that will fit them all.

The termite society, as that of the ants and bees, is built on the caste system, but otherwise it has no likeness to that of these other social insects. The termites are related to the cockroaches, and have developed their own social ways.

The newly matured winged males and females swarm out of the nest in the spring and associate in pairs to found new colonies. The two of a voluntarily wedded pair drop to the earth, break off their wings as useless organs for future underground life, and together excavate a hole in the ground. Here copulation takes place, and the queen then proceeds with her business of egg laying. From the eggs are produced five different forms of individuals characteristic of the termite colony. The first form is that of the parent pair, known as the king and queen, that founded the colony, or their successors. Next are two potentially fertile forms termed "supplemental reproductives." One of these has wing pads, or undeveloped wings; the other is wingless. The function of the supplementals is to replace the primary king or queen if anything happens to them. This is a wise provision that the other social insects have failed to make. Termites of the fourth and fifth kinds are true castes; those of the first are workers; those of the second are soldiers. Individuals of these castes are wingless young forms, or nymphs, arrested in their development, having nonfunctional reproductive organs, but structurally constituted for their respective duties.

Though the primary food of the termites is dead wood or other dead vegetable matter, the members of the colony have an elaborate system of feeding one another with products of their own digestion. Such substances include saliva, regurgitated food, feces, and particularly exudates from their skin which are licked off by other members of the colony. The exudates of the queen are most copious and the most highly desired. The queen therefore is always surrounded by a host of licking workers. In some species she becomes enormously enlarged with age and the development of her ovaries. It is this mutual food exchange that binds the members of the colony together.

If a colony loses its king or queen, or both, supplementary reproductives are produced within a short time to take their places. When the new royalty is established, the production of supplementals ceases, and the surplus secondaries are eaten by the workers. Apparently the presence of a pair of functional reproductives exerts some inhibiting influence throughout the colony that prevents the development of unnecessary secondary reproductives. Lüscher (1952) found that the inhibitory effect is potent only when the workers can in some way touch the functional reproductives. He proposes therefore that it is the saliva, feces, or exudates of the latter that contain some ingredient, possibly an ectohormone, that is the active inhibiting agent. This suggestion is quite in line with the recent finding that a "queen substance" obtained by honey bee workers from their queen inhibits the development of the ovaries in the workers and prevents the rearing of new queens. It seems a strange coincidence, then, that insects so far apart as the termites and honey bees should have developed the same device for regulating the activities of the colony.

THE ANTS

On a warm spring day swarms of winged ants may be seen fluttering through the air. These are mature males and females on their nuptial flight, during which mating takes place. A female after being fertilized descends to the earth, breaks off her wings, looks for a hole in a protected place, or herself digs a small cavity in the ground. She then closes the hole over her and remains a self-imposed prisoner until the eggs develop in her ovaries. During this time she is nourished on the products of her own degenerating wing muscles dissolved in her blood. When the ripened eggs are laid and hatch, this issuing first brood of young larvae are fed saliva by the queen until they transform to pupae. The first adults that come from these underfed larvae are necessarily small; they are sterile wingless forms destined to become workers, which are the ordinary ants seen about an anthill. They go out of the nest foraging for food for themselves and their mother. The latter then lays more eggs which produce later broods of better fed larvae that give rise to larger adults. The queen continues with her egg laying and the colony grows rapidly as the workers enlarge the nest. Eventually there will be thousands of active workers in the colony. The workers of some species may be of several sizes, the largest being known as soldiers. The next spring winged fully adult males and females appear, ready to disperse and found new colonies.

Caste determination in the ants is still not fully understood. So many explanations have been offered to explain it that we cannot feel safe at present in accepting any one as final.

The ant queen is not as autocratic as the honey bee queen. She will tolerate her own mature daughters in the nest, and fertilized daughters sometimes return to their home nest and increase its population. A queen is said to live normally for 12 to 17 years; though she is fertilized but once, she continues egg laying until her death. The males die soon after mating; the father of a colony never sees his children. The life of a worker is usually about 3 or 4 years, but some are recorded as living for 6 years. The ants do not construct cells for the brood as do the social wasps and bees. The larvae are kept on the floor of an open chamber of the nest, from which they can readily be removed in case of danger, as, for example, should the nest be invaded by raiders, or disrupted by man or some other animal.

Ants in general are omnivorous, feeding on both animal and vegetable food. Some collect seeds and store them in the nest, others are true agriculturists. Members of the latter may often be seen carrying pieces of leaves to the nest. Within the nest they cut up the leaves and pile them in beds, on which in the damp underground chamber a fungus grows. The fungus spores are eaten by the adult ants and fed to the larvae. When a virgin queen of these ants is about to leave the nest, she fills a pocket beneath her mouth with some of the fungus and carries it with her until she is mated and starts a home of her own. In this way each species maintains a culture of its particular kind of fungus.

Many ants feed largely on honeydew, which they find on the leaves of trees or get directly from the aphids, or plant lice, that make it. Honeydew is a liquid fecal discharge of aphids and other sap-sucking species containing a concentrate of the excess sugar they take in with the sap of the plants on which they feed. Nevertheless, this "honeydew" is much sought after by the ants, and many of them have learned that by stroking the aphids with their antennae, the latter may be induced to evacuate a drop of their sugary excrement. Furthermore, some ants collect the fall eggs of the aphids and keep them over winter in their nests. In the spring they distribute the young aphids on plants for feeding, those of tree species on the leaves of trees, those of root species on the roots of their proper food plants, particularly corn. This complex behavior is hard to explain as mere instinct, and has led some entomologists to declare that the ants are the most intelligent of all insects. In fact, few other animals could remember through the winter where they got the eggs.

Finally, certain individuals of some ant species engorge themselves to such an extent on honeydew that the abdomen becomes a great inflated sphere. These individuals are no longer able to walk, so they suspend themselves by their legs from the roof of the nest chamber. Here they hang and serve as foodstores for the others. On being

stroked by a hungry worker, they respond by regurgitating droplets of their honeydew. It is not explained whether these "repletes," as they are called, voluntarily offer themselves as colony food bags, or get that way because of their greed for honeydew.

As already noted, in any society there must be some bond that holds the members together. With the ants as with the termites, the bond appears to be mutual food exchange between individuals. The adult ants exchange regurgitated food, and the young larvae may be fed in the same manner, though most larvae can eat solid food. The larvae themselves, however, produce exudates from the skin and salivary secretion that appeal to their adult nurses, and are also much in demand by the other workers and the queen. The larvae thus get much attention from all members of the colony. The ants therefore like one another in a very literal (gustatory) sense. Furthermore, various other insects that have agreeable exudations to offer live as welcome guests or as permanent residents in the ant nest.

There are species of ants that have acquired the name of "slave-makers," but they are really kidnapers, and as such they demand no ransom. They raid the nests of some other species and carry off older larvae and pupae to their own nest. When the adults of the captured species emerge they at once assume the duties of workers, being entirely unaware that they are in a strange nest, and the captors treat them as members of their own species. The "slaves" therefore suffer no more than a change of nests, and in some cases they become more numerous than the nest owners.

Then there are the so-called amazon ants, named not from the river but from those famous female fighters of fiction. The females of the species are armed with such long, sharp, curved mandibles that they cannot construct a nest of their own. The fertilized queen therefore insinuates herself into the nest of another species, perhaps kills the nest queen, and becomes accepted in the host colony. The workers of her own brood do no work in the nest, but raid other nests and bring home immature stages. These on maturity become the foraging workers of the colony and do not take part in the raids. Such colonies thus come to include raiding individuals of one species, and ordinary workers of another species.

All ants do not live underground. There are, for example, the famous army ants of the Tropics that live for the most part on the surface. Though these ants are called army ants, they do not go out to fight battles. Vast numbers of them together carry out foraging raids on the territory around the nest. Almost every small ground-living creature that cannot escape is captured, killed, and carried off as food; even young nestling birds may be attacked, and humans do best to step lively. The biology of the army ants on Barro Colorado

Island in the Panama Canal Zone has been extensively studied by T. C. Schneirla (1956), and a good résumé of the life and habits of the ants is given by Schneirla and Piel (1948).

The "nests" of the army ants are dense masses of the insects themselves, thousands of them closely clinging to one another by the claws of their hind legs, and hanging up beneath some shelter. Within this living mass of workers are the queen and larvae. The nest, however, is not a mere mass assemblage of workers; it is formed in a methodical manner. The first ants to arrive at a nesting site hang head downward from a support by the claws of their hind legs. The next crawl down headfirst over these, and so on until long strings of ants are formed reaching to the ground. Then the intervening spaces are filled, and the queen is housed in the upper part of the mass.

During the period of brood production, a nest may be maintained at one place as long as 3 weeks. The greatly swollen queen now deposits her eggs, which soon hatch and the larvae mature. At this time little raiding is done. When the new workers mature, however, they seem to stimulate the others to renewed activity, and raiding begins on a large scale, to continue for another 2 weeks or more. During the raiding period, a new nest, or bivouac, is formed every night somewhere along the line of march. At dusk the massed workers of the old nest disentangle themselves and the host swarms out in army fashion to find a new site, the end of the column being brought up by workers carrying larvae, and finally the queen with a band of attendants. From the new bivouac the raiders depart at dawn the next morning.

We have long been advised to consider the ways of the ant and be wise. The ways of the ant, however, are past understanding. The Micheners (1951, p. 240) have well said, "It is as foolish and futile to advise men to look to the ants or the bees for wisdom in social economy as it is to expect the insects to learn from man." G. C. Wheeler (1957) has also stressed the foolishness of Solomon's advice. Of course, we can learn a lot about the insects and their ways, but mere knowledge of facts is not wisdom.

THE BEES

The bees include both solitary and social species. Societies have been developed independently in various groups of bees, but they have become best organized among the bumble bees (*Bombus*), the so-called stingless bees (*Melipona* and *Trigona*), and the honey bees (*Apis*). Even these three groups, however, have little in common in their social systems, which probably have been evolved separately from solitary ancestors. The bees have one advantage over the termites, the ants, and the social wasps, which is that they produce their own nest-building material, wax, from glands in their bodies.

The bumble bees.—The bumble bees make their nests in the ground. Each colony is started anew in the spring by a fertilized female that has survived the winter in some protected place. The bumble bee queen is a perfect female of her species; she has highly developed ovaries, is equipped with wax glands on the abdomen, both dorsal and ventral, and pollen-collecting organs on her hind legs. She is thus able alone to start a colony and care for the young until the first brood matures. By contrast the honey bee queen can do nothing but mate and lay eggs.

On emergence in the spring from her winter seclusion, the bumble bee queen finds a small hole in the ground suitable for a nest. On the floor she builds up a mound of pollen moistened with honey, constructs a wax cup on top of it, and in this deposits her first eggs. In the manner of a bird she keeps the eggs warm by sitting on them until they hatch. To provide food for herself during the brooding season, the queen constructs a waxen pot in the nest which she fills with honey. The emerging larvae are fed by their mother until they transform to pupae. Because of the relative scarcity of food the first adults are small. They are all females; there being no males to attract them, they become workers and proceed with enlarging the nest and collecting pollen and nectar. The queen now devotes herself entirely to egg laying. As the colony thus grows the workers feed and care for the new larvae, and, since the latter are better fed than those of the first brood, they develop into normal adults of both sexes. Mating now takes place, and the fertilized females leave the nest in the fall to find outside quarters for the winter. As cold weather comes on, the old queen dies and the colony comes to an end.

The social instincts of the bumblee bees appear to be less rigid than those of the honey bees. The bumble bee workers sometimes assert their feminine rights by laying eggs. This, according to Free and Butler (1959), seems to infuriate the old queen, and even the workers begin to quarrel among themselves. It is said by Free (1955) that when males and females are being produced, some of the workers even try to snatch the eggs as they are laid by the queen, and eat them if successful. Here is a rare case of social order among the insects getting out of hand, showing that instinct may be disrupted when authority becomes lax.

The stingless bees.—Members of the bee subfamily Meliponinae are called stingless because they do not sting, but they do have very small harmless stings. They live in tropical regions; their principal interest here is that they show how different may be the social organizations of different kinds of bees. Most stingless bees build their nests in hollow trees, but some in the ground. The nest is constructed of wax, which in these bees is produced by both the females (sterile

workers) and the males from dorsal glands of the abdomen. The nest has a brood compartment in which the larvae are reared, and a food-storage compartment equipped with waxen pots for honey and pollen. The brood combs are horizontal, one above the other, like those of the paper-making wasps except that the cells open upward. The larvae are fed as are those of the solitary bees with one supply of food put into the cell with an egg, after which the cell is permanently sealed. The queen of the colony becomes so distended with eggs that she cannot fly out. New colonies therefore are formed by young females and a swarm of workers. With the honey bee (*Apis*) it is the old queen that leaves with a swarm. Though the stingless bees do not sting, as honey producers they have no economic value.

The honey bees.—The best known of the social insects is the ordinary honey bee, *Apis mellifera*. The modern honey bees live a somewhat artificial life in hives prepared for them by the beekeeper and furnished with prefabricated comb foundation. Formerly the bees made their homes in hollow tree trunks or suspended their combs from the branches, as some still do, but their nature has not been changed by civilization. The beekeeper has taught nothing new to the bees, and is forced to adapt his apicultural practice to the unchangeable ways of the insects.

The honey bees have developed the most strongly organized society of all the social insects, and we must concede that their system at least works better in some ways than our own. They have assured uniformity of inheritance by the workers through limiting reproduction to the queen, and they have eliminated juvenile delinquency by rearing the young in individual cells. Since the workers are sterilized, there are no illegitimate children. The bee colony has no crime problem, no strikes, no revolutions, and hence no need of a police force except for external defense. It may be argued, of course, that since no superbee can be produced, the race has no chance of advancement; but the bee society is probably already as nearly perfect as it needs to be for the bees themselves. The beekeepers, however, think that for their purposes they might improve their stock by controlled mating of the queen. When a virgin queen leaves the hive to consort with males, she flies up in the air and accepts the first male that catches her, and she may even mate with several males in succession. To counteract this promiscuity on the part of the young queens, the beekeepers have now perfected an instrument for artificial insemination of a queen from a selected male. The results have not yet been publicized.

The personnel of the beehive is fairly simple, there being only three castes—the queen, the workers, and the males, or drones. The workers

are all sterile females produced from fertilized eggs, the drones are normal males but come from unfertilized eggs. This is a curious condition for which the geneticists have explanations, but we may here be satisfied with the facts. If the workers do sometimes lay eggs, being unfertilized they produce only drones. A colony of thousands of insects working together must do some of the same things that we do, but the bees do them by methods very different from our own. They have, for example, no spoken language, but they must communicate, so they have a language of their own, two languages in fact, one a chemical language, the other a sign language. The workers have tools for various purposes, but their tools are parts of their bodies and are never mislaid or lost when wanted. The bees have the capacity for learning things they need to know that instinct cannot tell them. For example, they learn to recognize their own hive by observing landmarks, and they learn the position of food in the field. Their ability to retain what they learn implies that they have a faculty akin to memory; but we do not know the mental mechanism of the bees and cannot assume it is anything like our own or that bees have any degree of consciousness. The behavior of insects in general appears to be automatic reactions to sensory stimuli.

In nature the honey bees construct vertically hanging combs with horizontal cells on each side. In the hive colony the beekeeper expedites the work of comb building by furnishing frames of comb foundation stamped with hexagonal facets the size of the natural comb cells. The workers then hang themselves up in curtainlike clusters and complete the cells. Their building material, wax, is discharged from glands on the underside of the abdomen into pockets from which the bees extract it. In the completed comb, cells designed for the brood occupy the lower part and cells for food storage the upper part. The brood-comb cells are of two sizes. The queen now lays fertilized eggs in the smaller cells, unfertilized eggs in the larger ones. She retains throughout her lifetime a store of live spermatozoa in a small sac, the spermatheca, opening into the egg passage. She first inspects a cell by thrusting her head into it, then turns around and lays an egg in it. It has been supposed that the size of the cell determines whether the egg is to be fertilized or not, but this does not explain how the queen regulates the discharge of sperm. A recent idea is that sense organs on the antennae activate or inhibit the mechanism of sperm ejection, but probably the matter is still the secret of the queen. In any case, fertilized eggs develop into female workers; unfertilized eggs into drones.

When the eggs hatch, the younger workers already present in the hive assume the role of nurses whose duty it is to feed the larvae. For this duty they are provided with glands in the head that secrete a rich

food material known as royal jelly, which is discharged on a small plate of the hypopharynx between the bases of the mouth parts. Worker and drone larvae are fed for 2 days on royal jelly and are then given honey and pollen. When the larvae are full grown and ready to change into pupae, the cells are closed with wax cappings.

For the rearing of queens the workers construct a few large cells hanging vertically from the edges of the comb. In these cells the queen deposits a fertilized egg, and the issuing larvae are fed entirely on royal jelly. An ordinary young worker larva will develop into a queen in a queen cell, and it is generally supposed that a female larva becomes a queen on account of the rich diet she receives. The honey bee queen, however, is not a perfect female bee, as is the queen bumble bee. She has greatly developed ovaries, but she lacks the food glands, wax glands, and pollen-collecting apparatus of the workers. The larva in the queen cell therefore must receive some inhibitory substance along with the royal jelly, but what this may be has not yet been discovered.

The last duty of the workers is foraging outside the hive for nectar and pollen. Nectar sucked from the flowers is retained in the crop, a saclike enlargement of the esophagus, and is thus transported to the hive, where, mixed with saliva, it becomes honey, which is then stored in a comb cell. Pollen, scattered over the bee's body from the flowers visited, is first scraped back to the hind legs, where, by a special apparatus on the base of the tarsus, it is packed into baskets on the outer sides of the broad femora and carried to the hive. All this the workers know how to do without learning or training. What a fine thing it must be to know by instinct, and not have to go to school to learn a trade or profession.

Still more remarkable is the way foraging bees coming to the hive with a load of nectar or pollen are able to tell the other bees where they got it and how to find more of the same. Here they make use of their sign language, supplemented by their chemical language, which has been translated for us by Von Frisch into German and rendered into English (Von Frisch, 1955).

It would make too long a story to go into all the details by which Von Frisch learned the sign language of the bees. Briefly his results are as follows. The foraging bee on returning to the hive either with nectar or pollen, after depositing her load, makes a run-around on the comb, called a dance. If she has not been far from the hive she wildly swings around in small circles, now to the right, then to the left. The surrounding bees become greatly excited, follow the dancer, and touch her with their antennae. Thus they get the scent of the nectar or pollen adhering to her body and rush out to find the corresponding flowers. If, however, the forager has been

much farther afield, she does another kind of dance. In this dance she makes two adjoining circles, returning at each round along a straight line between them, and at the same time making vigorous wagging movements of her abdomen. This dance tells the other bees they must go a long distance, and more, that the incline of the straight line of the dance on the vertical comb indicates the angle their flight must keep with the direction of the sun. But what if the sun is hidden by a cloud? If there is a patch of clear sky, the bees are not disconcerted. The sky always reflects polarized light, and the compound eyes of the bees are so constructed that they register polarized light and its plane of vibration. Polarized light from the sky then becomes the bee's guide instead of the sun itself. It truly seems almost incredible that the bees can have so much seeming intelligence, but Von Frisch has fully demonstrated his findings by numerous observations and experiments. It is well known that other insects are able to guide themselves on a straight course by the sun; it is the special achievement of the bees that they can tell each other what angle to keep with the sun in order to arrive at a particular destination.

As long as the queen is present in the hive, all goes well with the colony. The queen will not tolerate another queen; if one matures in a queen cell she is driven out or assassinated. This is not an act of jealousy or vengeance; it is just something the queen has to do to preserve order in the hive. The workers are constantly informed of the presence of the queen. She is always surrounded by a crowd of interested workers that feed her, and lick her as if they get some highly agreeable taste from her body. Butler (1954, 1955a, 1955b) and his associates have shown that, in fact, the workers obtain a substance from the queen, apparently produced by her mandibular glands (Butler and Simpson, 1958). Then, by reason of their habit of exchanging food with one another, this "queen substance" is quickly passed around to all the workers in the hive. By this chemical language, or queen taste, the workers are kept informed of the presence of their queen. The queen substance also appears to inhibit the development of the ovaries of the workers.

If now the queen leaves the hive with a swarm of workers to found a new colony, or if she becomes finally exhausted and dies, the workers soon know that they are queenless and must prepare for rearing a new queen. So they remodel a worker cell containing a young larva into a queen cell, and give this larva a queen's diet. The larva being a female develops into a replacement queen. Some of the workers at this time, being released from the inhibitory effect of the queen substance, may reassert their femininity and begin laying eggs; but they produce only drones, of which there are already more than enough in

the hive. At the end of the season the superfluous drones are driven out or killed, according to the law of bee society.

The bees keep the hive scrupulously clean, but against bacterial diseases that infect the larvae they have developed no defense of their own. For disease eradication, therefore, they are dependent on the beekeeper who now treats the hive with some of the "wonder drugs" of human medical science. Here we score one over the bees.

While emphasis has been given to the fact that peace and order prevail among the members of the bee colony, we must not neglect to add that the bees do not extend their moral code to their neighbors. They have no compunction about raiding and robbing another hive. In this we see a close parallel with the international behavior of the human species.

HUMAN SOCIETY

Of all the vertebrate animals, modern man is the only species that lives in organized societies in which the members are interdependent on one another. Prairie dogs may live in large communities comparable to human towns, but the members are independent individuals. There is, however, the palm-chat, a bird of Haiti, described by Wetmore and Swales (1931), that builds huge communal nests in which a number of pairs have separate nesting rooms. The inhabitants may be likened to the dwellers of an apartment house that they themselves have built, but it is not known that they have any other relations with one another.

Human society has some parallelisms with insect societies, but fundamentally the two are entirely different. The caste system, for example, has prevailed in human societies, but human castes are determined by social levels, and are not differentiated structurally according to the work they have to do. We are at least gregarious, few care to live alone, and most people want to be members of some group within the society, a political party, a church, a club, a labor union, or a gang. However, we are bound together by economic necessity, not by brotherly love. We are not adapted to social living by any instinct, as are the social insects. Whatever remnant of an instinct we do have is that of the solitary animal that looks out for his own welfare, even if this involves robbing and fighting members of his own species. Such actions are not crime with the solitary animal; they lead to the survival of the fittest. The primitive instinct of every child is "me first."

We pretend that as adults we regulate our actions by reason, and so we may. Reason can dictate that the only way for members of a community to live together is for each one to follow the Golden Rule; on the other hand, it can suggest that advantages may be had by ignoring it. Reason therefore can lead to quite opposite kinds of behavior.

The social insects have achieved uniformity of behavior in the workers of the colony by limiting the reproductive function to one fertile female; in human societies each member is potentially reproductive, so we have in every community all kinds of individuals—good, bad, and indifferent. Crime therefore has always plagued human society (ever since Cain slew Abel), and no police force can suppress it. The production of antisocial members in human societies is an unavoidable byproduct of freedom of the individual. So today we have not only thieves and murderers, but crooks of many kinds in business, in politics, in the professions, in labor unions, and in the general populace. Since many in this class are outside the law, or successfully evade it, they may prosper better than the honest citizen. Hence they are not eliminated by natural selection, as would be unfit members of any nonsocial species of animal. Though individual liberty is our most cherished inheritance, it is also the root of much of our trouble.

In our favor it must be pointed out that it is freedom of the individual that has led to the advancement of the human race as a whole. We are individualists by inheritance from progenitors that were solitary animals, and even a dictator with the most ruthless methods of control cannot make all members of the tribe willing conformists to a system that would abolish individual liberties. By contrast, the social bees with their immutable instincts and absolute regimentation have probably been the same since before man became man, and they are destined to continue as they are as long as they exist.

It is certain that reason did not produce the first human societies. The history of man as known from human fossil remains goes back for nearly a million years. Species of men lived all through the ice ages of the geologic period known as the Pleistocene, and included several so-called apemen as well as species of *Homo*, among which were the ancestors of modern man. Comparative anatomy shows unquestionably that we are somehow related to the monkeys and apes, though not directly to any modern species of these animals. There can be little doubt that we inherited our fingers, our abbreviated tail-bones, and the ability to stand upright from some apelike progenitor. The anthropologists have picked on a fossil ape of the Miocene, named *Proconsul*, as the nearest approach of any ape to man.

If our prehuman progenitors were apelike creatures, it seems reasonable to suppose that our form of society had its origin in some behavior characteristic of the apes. The only social groups known among modern apes are families consisting of a dominant male and several submissive females, together with their young. So it is theorized that the first apemen that left the trees brought their females with them and established their harems on the ground. Anthropolo-

gists have named this first fossil man *Australopithecus*. Later, for mutual protection or for hunting and killing large animals for food, families united into tribes. Then some kind of internal order had to be preserved, and dominant males became tribal chiefs. (It may be noted that males are still dominant in government and politics.) Instead of fights among members of a tribe, wars now broke out between tribes, and have continued to the present when tribes have become nations. It would be interesting to know something of the appearance and accomplishments of these early apemen, whether they were covered with fur or were naked, and if they had a language, but bones tell nothing of these things. Modern "restorations" of fossil men suggest that they were rather homely creatures. We do know that primitive men very early made tools of stone and flint, and probably had weapons with which they could secure animals for food.

Along with the apemen there lived, during the Pleistocene, species of the genus *Homo*, including *H. rhodesiensis* in Africa, *H. neanderthalensis* in southern Europe, western Asia, and northern Africa, and *H. sapiens*, our own ancestors (presumably derived from Adam and Eve). Of all these members of the family Hominidae, *Homo sapiens* alone survived the Pleistocene. We can feel therefore that our species must have been in some important way superior to the others.

Man's first use of his fingers and brain was in the making of stone and flint tools. In the course of time he successively improved his flint implements until he learned to make fire. Then he found copper, next produced bronze by adding tin, and finally discovered iron. The subsequent history of the human race through the age of gunpowder to the splitting of the atom is the story of *Homo sapiens*, which is told in the history books.

Probably the greatest asset that *Homo sapiens* possesses is spoken language. The vocalizations of other animals are merely expressions of emotions; only man makes sounds that stand for names of things. Man is thus the only animal that can transmit information, except by example and inherited instinct, from one generation to the next. Human education, moreover, is greatly facilitated by the long juvenile period of growth and brain development. Without language, and its written symbols, we should be little better than dumb animals.

Finally we come to what distinguishes *Homo sapiens* uniquely from all the other animals. This is his ability to supplement his native talents with artifacts from flint tools to airplanes. All this he owes to his brain development, his manual dexterity, his accurate eyesight, and his language. Hence our species has undergone much anatomical evolution since the days of the apeman. (See Spuhler, 1959.) Linnaeus gave modern man the name of *sapiens*, the knowing one, about 1758, when man had learned something about himself, the world he

lived in, and the universe around him. From the beginning, however, man's supreme faculty has been his creative imagination; even the making of a flint tool required some degree of visualization.

Throughout human history imagination has prevailed over reason. Down to the modern scientific period, observed natural facts have been explained by the invention of myths and superstitions. Though in recent times man has made strenuous efforts to eliminate his ignorance, he still does not know everything, and even today in some quarters fiction is more honored than facts. Yet it is to imagination that we owe some of the best products of the human mind, such as art, architecture, music, religion, and much of literature. Without these embellishments the practicalities of life would be hard to endure.

From this brief review of human civilization we can admit that our form of society is far from perfect, and it would seem that the social insects can have no cause to envy us. In addition to juvenile delinquency, crime, political squabbles, and revolutions, we have the still more deplorable lack of international harmony. The fires of nationalism perpetually burning beneath the surface are ever ready to erupt in the surge of some nation to subdue its neighbors or to dominate the world. Still with all this, so long as we maintain individual freedom we should not care to exchange places with the insects.

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Luminescence in Marine Organisms¹

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THE study of bioluminescence, or light production by plants and animals, has made rapid strides as new and highly sensitive light detectors have become available. The subject is of interest for a number of reasons, among which appeal to the imagination may well be included. Bioluminescence is a specialized function exhibited by a small minority of species, yet among them there is a great diversity of forms. It must therefore have developed independently in the course of evolution in species that have little else in common. An exception is that in the deep sea, where sunlight does not penetrate, most of the organisms that have been observed are luminescent. Here, as elsewhere, it appears that luminescence, at least in its more highly developed forms, is of biological value to many of the species that possess it. Finally, the subject is one that gains from being viewed as a whole. The chemistry of bioluminescence, coupled with the fact that luminescence is shown by many bacteria for which it has no biological significance, provides a clue to its origin. This therefore is a good point from which to begin a survey of the subject.

CHEMISTRY OF LUMINESCENCE

The light of bacteria, as of other luminescent organisms, is emitted during the course of a chemical reaction when a luminous substrate, luciferin, is oxidized by an enzyme, luciferase, in the presence of molecular oxygen. The biochemical mechanism of this reaction has been determined, largely through the efforts of E. L. Stehler and his colleagues in Chicago. It turns out that the luciferin of bacteria is a flavin closely allied to a yellow pigment, riboflavin, also known as vitamin B₂ or vitamin G, which is itself luminescent. Bacterial luciferin is, in fact, an aldehyde complex of dihydroflavin mononucleotide. It is oxidized through the agency of luciferase to flavin

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mononucleotide. Oxidized luciferin is reduced by diphosphopyridine nucleotide, under the influence of a specific oxidase, and thus a constant supply of luciferin is maintained.

Many years ago it was suggested that luminescence in living organisms was derived from cellular respiratory mechanisms. This is borne out by the situation in luminous bacteria, in which light is emitted during the course of the reversible oxidation of a flavin complex. Riboflavin nucleotides participate as coenzymes in the oxidation-reduction reaction of cells. The light emitted during the oxidation of dihydroflavin mononucleotide in luminous bacteria can therefore be regarded as an accidental byproduct of the reaction. This situation helps us to understand how luminescence has appeared so frequently and independently throughout the animal kingdom, from unicellular protozoa to fishes. Presumably, slight changes in preexisting respiratory pathways have been exploited to achieve light production. There is a wood fungus, *Panus stipticus*, which exists in luminous and non-luminous forms, and luminosity is inherited as a single pair of characters dominant over nonluminosity. Thus, a slight change in genetic constitution may be enough to confer luminescence on an organism.

Other detailed biochemical investigations have been concerned with the luciferins of a small ostracod crustacean (*Cypridina*) and the firefly. Neither of these substances has yet been identified chemically with certainty, but enough is known about their composition to show that they are dissimilar from each other and from bacterial luciferin. It has just been demonstrated that the luciferin of the piddock (*Pholas*), a marine bivalve mollusk, is reduced flavin mononucleotide. Luminescence in *Pholas* thus conforms to the bacterial system.

There is obviously much diversity in the chemical composition of luciferins found in different creatures, and this is confirmed by other lines of evidence. Emission spectra of the luminescence of different creatures are often dissimilar, indicating that different substrates or luciferins are involved. Cross tests made with the luciferin of one animal and the luciferase of another have been positive, that is, have resulted in light emission only when the animals are closely related; e.g., different species of fireflies. Again, these results point to much specificity in the luciferins and luciferases of different groups. A curious exception concerns a small crustacean *Cypridina* and a fish *Apogon*, both from Japan. The luciferin of the one gives a positive cross-reaction with the luciferase of the other, and this is the only positive result that has been obtained, of many tried, with luciferin and luciferase of *Cypridina* against luminous extracts of other animals. It implies close similarity in the biochemical mechanisms of these two unrelated species.

MODES OF LUMINESCENCE

Three different ways of luminescing are employed by animals. By far the commonest is intracellular luminescence in which the animal produces light within special cells or photocytes. These are aggregated together at special positions, and often form part of complex light organs provided with reflectors, lenses, black pigmented sheaths and even with shutters in some instances. Complex light organs are found in deep-sea shrimps, squid, and fishes (pls. 1 and 2). Another form of luminescence consists of discharging a cloud of luminous matter into the sea water and we find this method in use among several quite distinct animals; namely, polychaete or bristleworms, squids, several bivalve mollusks (the group containing mussels, oysters, etc.), crustaceans (ostracods, mysids, and shrimps, allies of the water-flea and the lobster), and deep-sea fish (pl. 1, fig. 1, and pl. 3, fig. 2). The third method of luminescence involves a symbiotic relationship with luminous bacteria. The animal harbors these within special glandlike organs and supports them; in return, the bacteria produce light for their host. Luminous bacteria occur normally in certain squids and fishes.

A few animals, like bacteria, shine continuously, but in most animals light emission is discontinuous and is under reflex or voluntary control. Jellyfish, sea pens, and comb-jellies (or ctenophores; pl. 3, fig. 1), to cite a few examples, flash only when stimulated. The normal stimulus is touch or a mechanical shock, giving rise to a battery of impulses in the nervous network which characteristically forms the nervous system of these animals. The impulses pass to all parts of the animal and the light cells are excited and made to flash. Following excitation of a sea pen, waves of light can be seen running over the surface of the animal, these waves corresponding to the spread of excitation in the underlying nervous network.

For experimental and quantitative studies, the light emitted by animals can be recorded with the aid of photoelectric apparatus. This usually consists of highly sensitive photomultiplier tubes, amplifiers and cathode ray oscilloscopes or pen recorders. Indeed, the luminescent response can be treated like the classical nerve-muscle preparation, with the added advantage that certain features can be monitored or watched by the experimenter. For example, successive flashes can be distinguished, and the spread of luminescence can be followed.

Animals that shine or flash spontaneously include luminous crustaceans, fireflies, squid, and fish (pl. 1 and pl. 2, fig. 1). In the fireflies, which are, of course, beetles (Coleoptera), the onset and duration of flashing are controlled by nerve impulses proceeding from the ventral nerve cord. It had long been supposed that peripheral control of flashing in fireflies was exercised by regulating the admission of

oxygen through the tracheoles or air tubes to the light cells. Recent studies have undermined this hypothesis, and it now seems likely that nerve fibers supply the light cells directly. Nerve impulses concerned with flashing have been recorded from the ventral nerve cord, and it has been suggested that acetylcholine, released at the nerve ending, activates the light cells by releasing luciferin from an inhibitory complex. The introduction of this concept brings regulation of luminescence into line with neuromuscular physiology, where acetylcholine has long been accepted as a chemical transmitter between nerve endings and muscle fibers.

The lanterns of fishes are also under control of the central nervous system. Beebe found that lantern fish (myctophids) would respond by flashing, to the display of his luminous watch dial. Nervous pathways obviously exist from the eyes through the brain and spinal cord to the light organs scattered along the entire length of the fish. The terminal pathways, from the spinal cord to the periphery, lie in that part of the visceral nervous system known as the sympathetic, which supplies blood vessels, viscera, contractile pigment cells, and light organs.

Animals containing luminous bacteria also have mechanisms for dimming the light although the bacteria, being independent entities, are not subject to direct control. The light of the bacteria is cut off by rotating the organ out of sight, by drawing a screen over it, or by expanding dark pigment cells over the external surface. All these methods are utilized by fish. In squid the organ containing the bacteria is partially embedded in the ink sac, and the light is cut off by pressing a film of black ink over the outer surface of the light organ.

ILLUMINATION AND DIURNAL RHYTHMS

Most animals, when excited, flash at any time of the day or night. Since luminescent light is very faint, it is scarcely perceptible in daylight and can be regarded as biologically useless. Those animals which are nocturnal, or which live in dark places, or in the dark depths of the sea, are not troubled by this misplaced or mistimed behavior. There are some organisms, however, which flash only in darkness or at night, and investigations of dark adaptation and of diurnal rhythmicity have revealed many features of interest.

In some animals, notably sea pens, comb-jellies (pl. 3, fig. 1), and *Pyrosomae* (a colonial planktonic animal whose name means firebody; see pl. 4, fig. 1), the luminescent response is inhibited by light, and it is gradually restored when the animals are placed in darkness. It takes about 30 minutes for a sea pen or comb-jelly, previously exposed to light, to recover its luminescent ability in darkness. Details of the process have been worked out more fully in comb-jellies. Inhibition

occurs at two levels: illumination affects the excitatory mechanism so that the light cells are no longer excited, and it also decomposes the luminescent substrate within the light cells. The amount of illumination necessary to inhibit luminescence is a function of light intensity and duration of exposure, the product of the two being some constant which varies with the species (from about 5×10^3 to 60×10^3 meter-candle-minutes).

Luminescence in dinoflagellates (single-celled plants) is not only inhibited by light, but shows true diurnal rhythmicity, disappearing during the daytime and reappearing at night, even when the cells are kept under constant conditions. *Gonyaulax polyedra*, a species that has been studied intensively by Hastings and Sweeney, maintains a constant rhythm of luminescence for 14 days when cells are kept under dim light. The cells, when stimulated, commence flashing in the evening, and the response fades away at dawn. Several factors are responsible for this rhythmicity: some endogenous mechanism within the cell controls the timing of the rhythm; periodical changes occur in excitability of the cell; and diurnal fluctuations take place in intracellular levels of luciferin and luciferase, the amounts of which increase at night.

COLOR AND INTENSITY

The lights of most marine animals appear blue or blue green to our eyes. Jellyfish, siphonophores, various bristleworms, *Pyrosoma*, many squids and fish, show blue luminescence. The lights of sea pens, ctenophores or comb-jellies, polynoids, or scaleworms, and certain fish are blue green or green. Only rarely does the luminescence appear yellow or red—for example, in a few squid and fish. One deep-sea species of squid, *Thaumatolampas diadema*, has light organs which emit blue and red lights.

More instructive than color, which is a subjective impression, are relative spectral emission curves, which show the relative energy of light of different wavelengths (fig. 1). These curves are fairly steep and reveal that the emission is restricted to rather narrow spectral regions in the visible region. For blue and blue-green lights, the commonest ones observed, most of the energy is confined to narrow wavelengths between about 4,200 Å and 5,400 Å. Usually the curves are unimodal (i.e., possessing a single peak); occasionally there is a small secondary peak, of unknown significance, toward longer wavelengths.

These luminous emission spectra show reasonable similarity to the spectral sensitivity curves of the eyes of marine animals. Retinal sensitivity curves and action spectra are unimodal, fairly steeply peaked, with maxima in the blue-green or blue regions of the spectrum. Worms, shrimps, crabs, and squid are most sensitive to blue

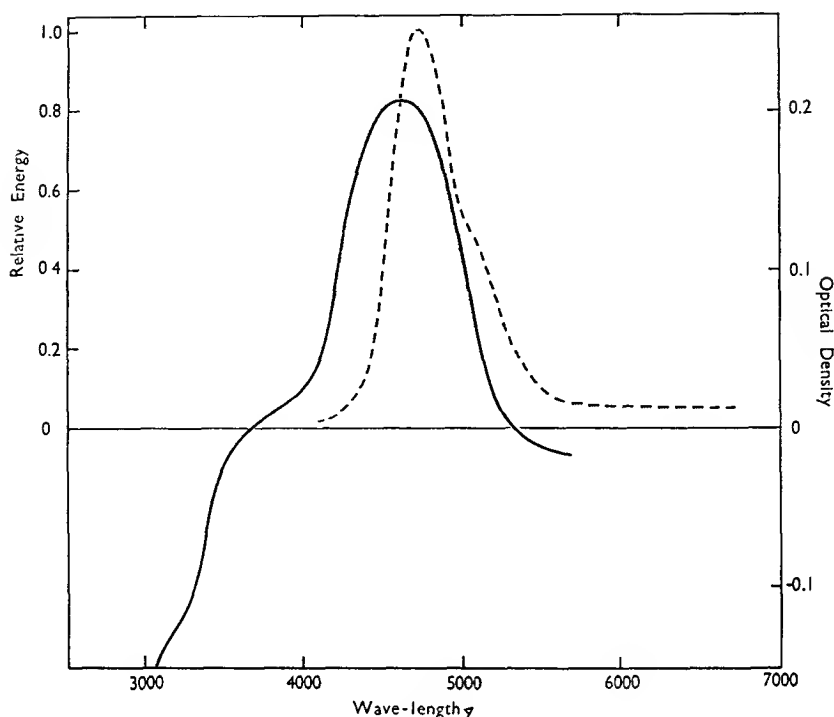


FIGURE 1.—Comparison of the spectral characteristics of luminescence and visual sensitivity of small oceanic shrimplike creatures known as euphausiids. The interrupted line shows the relative amounts of energy in the light emitted by a euphausiid *Thysanoessa raschii* at different wavelengths. The continuous line is a difference curve for the photo-sensitive pigment in the eye of another euphausiid, *Euphausia pacifica*. It is based on the difference between the absorption of unbleached and bleached pigments, and is an indication of the spectral composition of the light absorbed by the eye; values for this curve are shown to the right. Maximal light emission is at 4750 Å; maximal visual sensitivity is around 4600 Å.

light rays, and their spectral sensitivity curves have maxima from 4,750 Å to 4,900 Å. Inshore and surface fishes possess the visual pigment rhodopsin, with an absorption maximum around 5,000 Å. In terms of visual stimulation, therefore, the lights of most marine animals are very efficient, since all of their energy content lies in the visual range to which the eyes of marine animals are most sensitive. Figure 1 shows the close similarity existing between the emission spectrum of the light of euphausiids (small shrimps) and the absorption spectrum of rhodopsin from the same animals.

Animal lights are really very weak compared with, say, electric lamps. The intensities of some of these lights have now been measured. They range from 1×10^{-6} microwatt to 1×10^{-1} microwatt per cm. square of surface receiving the light at a distance of 1 cm. At the lower extreme are the weak flashes of single protozoans. The strongest luminescence is that of pelagic siphonophores, comb-jellies

(pl. 3, fig. 1), *Pyrosoma* (a colonial animal of the plankton; see pl. 4, fig. 1) and some deep-sea fish, the luminescence of which ranges from 1×10^{-4} to 1×10^{-1} microwatt per cm. square of light-receptor surface at 1 cm. distance.

To give these values some meaning in terms of human vision, it may be noted that the lowest intensity which man can see is of the order of 1×10^{-10} microwatt falling on 1 cm. square. Deep-sea fish certainly have eyes that are as sensitive as ours, perhaps more so; those of crustaceans are probably less efficient. From these values we can estimate how far these lights can be seen by other animals in sea water. The light from a single fish or other animal decreases with distance according to the inverse square law. The light from a single lantern fish can be seen by another fish at about 10 meters (10 m.); that of a marine crustacean such as *Euphausia* can be seen by another *Euphausia* at about 5 m. The bright light of a comb-jelly and a *Pyrosoma* can be seen by fish, or other animals with equally sensitive eyes, at distances of up to 100 m.

Many, but by no means all, deep-sea animals have dark liveries and are black or brown: for example deep-sea fish and jellyfish; others are bright scarlet or crimson, such as prawns or shrimps. There is little doubt that these are concealing colors that make the fish or other animal difficult to see. Light in the ocean depths comes from animal luminescence, and black surfaces serve to reduce telltale gleams to a minimum. The carotenoid pigment responsible for the red coloration of pelagic Crustacea reflects very little blue light, which forms such a preponderant part of animal luminescence, and is as effective as a black covering.

FUNCTIONS OF LUMINESCENCE

Terrestrial luminescent animals are nocturnal in their habits or live in dark places. Fireflies and glowworms use their lanterns as signals during mating, to bring the sexes together, and at least one luminous fungus gnat is carnivorous and attracts its prey by means of its lantern. These animals can be studied close at hand, with relative ease, but far different is the situation regarding luminous marine animals. Many of these, especially from deep waters, have never been seen alive; those that do survive capture rarely live long in captivity. Consequently, our ideas about the functions of luminescence in marine animals are mostly conjectures. Some of these seem reasonable and it should be possible to verify them by various means.

Luminous animals are of great diversity and habits. Similarly, we may expect their luminescence to be used in many different ways and to perform many roles. One role might be called static advertisement. There are many passive members of the plankton, such as jel-

lyfishes, siphonophores, comb-jellies (pl. 3, fig. 1), tunicates (pl. 4, fig. 1), etc., which flash brightly when they are mechanically stimulated. These creatures, of course, have their specialized enemies, but, by and large, they are left alone by large active swimmers. The light they produce outlines the entire body and so gives any creature bumping into them in the dark a chance to recognize them and steer clear. A somewhat similar function is served by the luminescence of sedentary animals on the bottom such as hydroids and sea pens. They flash or twinkle all over when touched, and thus warn would-be settlers that the territory is already occupied.

Some luminous animals, such as the paddleworm *Chaetopterus* (pl. 3, fig. 2), live in tubes, or burrows, and discharge a luminous secretion when disturbed. Intruders seeking dark crannies in which to lodge or deposit their eggs are thus warned that the owner is at home, and the luminescent light makes the place less attractive to an intruder. Polynoids or scale worms appear to use their light as a "sacrifice-lure." These worms have luminescent scales on the back; they cast them off if they are disturbed, and the scales continue flashing while the worm crawls away. A variation on this theme is encountered among deep-sea prawn and fish which discharge a luminous cloud when attacked. The flash of light momentarily blinds or distracts an attacker, while the producer beats a hasty retreat.

Some fish appear to use their lanterns for illuminating their surroundings when feeding or hunting. This is probably the function of the large light organs which lie underneath the eyes of fish such as *Anomalops* and *Stomias*. Many deep-sea fish possess luminous fishing lures on barbels or tentacles, which are displayed so as to attract prey within reach of their gaping jaws, for example, stomiatoids and ceratioids or angler-fishes. Others have batteries of light organs that serve the same purpose within their mouths and throats; e.g., *Chauliodus*.

Some marine animals live and migrate together in dense schools, and luminescence certainly plays a role in enabling the members of the school to keep together in the ocean depths. The firefly squid of Japan, *Watasenia scintillans*, which comes to the surface annually in large swarms, is an example. The flashing photophores which deck the arms and bodies of these squid keep the school together. Schools of flashing hatchetfish (pl. 2, fig. 1) and lantern fish were seen by Beebe during his deep-sea descents. Euphausiids are another group of luminous marine animals that occur in vast schools. These animals make vertical migrations toward the surface each evening, and are believed to be one of the agents responsible for the deep-scattering layers recorded on echo sounders. Euphausiids bear batteries of photophores which enable them to signal to one another, and from the



1. A deep-sea red shrimp, *Systellaspis*, that discharges a luminous cloud when disturbed, and possesses light organs as well. The light organs appear as black spots and stripes along the sides of the body and on the legs. This shrimp is about 7 cm. long.



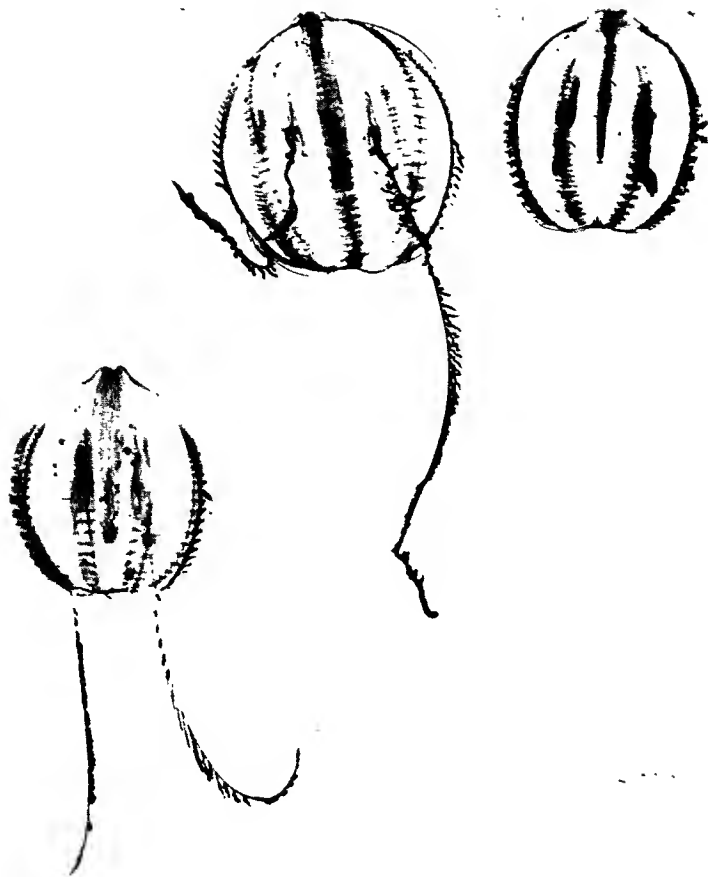
2. Head and tentacles of a deep-sea squid, *Pyroteuthis*, showing light organs around the eye. In life this animal is about 5 cm. long.



1. The hatchetfish, *Argyropspectus*. This is a luminous fish, about 4 cm. long, that bears a series of light organs along its ventral keel. The sides of the animal in life are metallic, like silver; it inhabits medium depths, around 700 m.



2. A deep-sea fish, *Stenias ferox*, possessing three kinds of light organs, namely, a luminous barbel under the chin, a searchlight under the eye, and a series of bull's-eye lanterns along the flanks. Length, 17 cm.



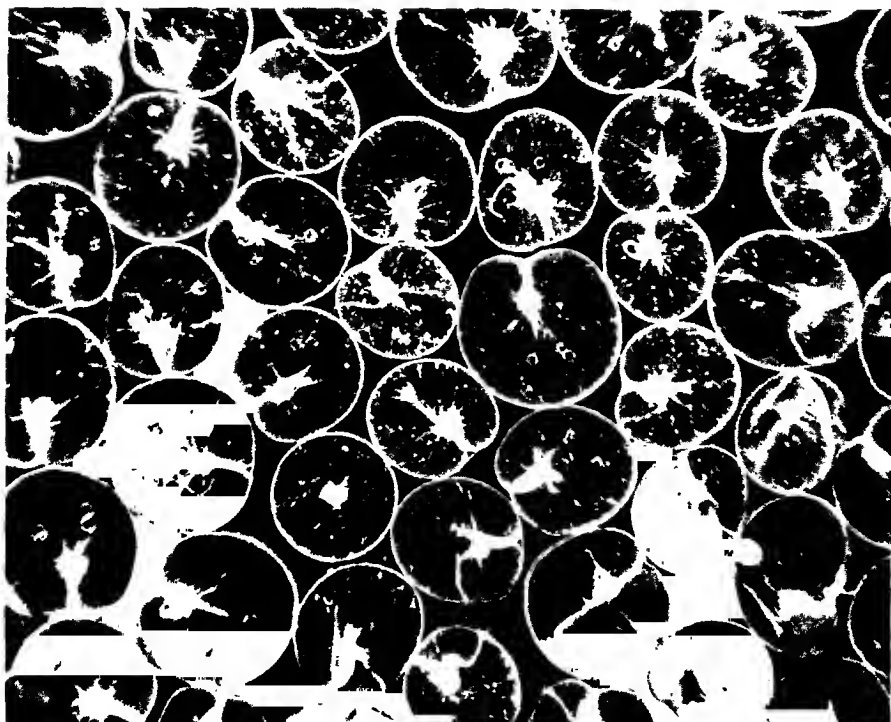
1. Comb-jellies (ctenophores, *Pleurobrachia*), brightly luminous denizens of the plankton, often occurring in swarms. Light appears as flashes along the radial combs which run from top to bottom of the animal. Size, 2 cm.



2. The paddleworm *Chaetopterus*. This animal lives in a parchment tube on the sea bottom and discharges a luminous cloud when disturbed. Length, 10 cm.



1. A brightly luminous colonial sea squirt, *Pyrosoma*. The colony is made up of many luminous individuals, inhabiting a common casing. Colonies reach a length in the neighborhood of 500 cm.



2. Living cells of *Nautilia nautis*, a single-celled animal that sometimes swarms in immense numbers at the surface of the sea and produces bright luminous displays. It is one of several creatures responsible for "phosphorescent" seas. Each organism or cell is about 1 mm in diameter.

data already considered, we can estimate that the maximal distance at which the members of a school can be dispersed and still see one another is about 5 m.

Another function of luminescence is certainly connected with reproduction. In deep-sea crustaceans, squid, and fishes, the two sexes sometimes have characteristic and distinct patterns of light organs. These enable the species and sex of any animal to be recognized, and attract the males to the females for spawning purposes. We must also recognize, however, that many deep-sea animals, including fishes, are solitary hunters. The light organs of these species may be concerned with repelling the members of the species from one another, and keeping them spread out in hunting territories, the limits of which are regulated by the distances at which their lights can be recognized.

Voyagers who have sailed over tropical seas have given many accounts of great "phosphorescent" displays which they have observed, when large areas of the sea surface appear to glow with light. These great displays of luminescence are produced by dense aggregations of animals such as Noctilucae, comb-jellies, and Pyrosomae (pl. 4, fig. 1). We may well wonder what the biological significance of such luminescent displays may be. The intensity of light from a very large surface area diminishes with distance according to the extinction coefficient of sea water, in contrast to a point source, the intensity of which diminishes in proportion to the square of the distance and according to the extinction coefficient. Clear oceanic water is very transmissive, passing about 95 percent of blue light per meter depth. The light from a luminescent sea, having an intensity of, say, 1×10^{-2} microwatt at the surface would be reduced to about 1×10^{-4} microwatt per cm. square receptor surface at 100 m. These intensities are well above the threshold of vision; moreover they appear to lie in the range of light intensities which affect the vertical migrations of marine animals. Many free-swimming animals, especially crustaceans, squid, and fish, make these vertical movements, coming toward the surface at dusk and descending into the depths at dawn. The chief factor controlling the movements appears to be light intensity, the animals following some optimal light intensity or isolume. Many years ago Prof. A. C. Hardy pointed out that animals tend to avoid dense surface aggregations of certain kinds of plankton, and he advanced a hypothesis of "mutual exclusion." When the light beneath a surface display of luminescence is bright enough, the ascent of migrating animals may be halted. Differences in the directions of surface and deeper currents may then bring about further separation of the animal populations.

When W. Beebe and O. Barton made their famous descent in a Bathysphere 26 years ago, they observed a wealth of luminous animals in the ocean depths, often as abundant as the stars in the sky on a

moonless night. Particularly noteworthy were their observations on the schooling of luminous fishes, and the colors and mode of action of different kinds of light organs. Many deeper dives have been made since then in Bathyscaphes, and the biological results have been concerned especially with the vertical distribution of oceanic species. Another line of attack has been to send down protected photomultiplier tubes and cameras, that are triggered by luminous flashes, into the depths. Photomultipliers sent down to 3,750 m. (about $2\frac{1}{2}$ miles) by Clarke have provided information about the density and vertical distribution of luminescent animals. In a region of maximal luminescence at 900 m., flashing occurred at rates of 160 per minute, providing an almost continuous background light having a radiant flux greater than 1×10^{-7} microwatt per cm. square receptor surface. Such observations serve to emphasize the ubiquitous and constant occurrence of luminescence in the ocean depths, below levels reached by daylight, and the important part it must play in the lives of marine animals inhabiting those regions.

Trumpets in the West¹

By WILLIAM B. MORSE

*Field Representative
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[With 3 plates]

ONE of the most difficult problems in wildlife management is to protect and save a vanishing bird species. Many conservationists and agencies are participating in heroic efforts to safeguard the whooping crane, and that issue is still in doubt. There is another bird, once almost as near extinction, that has been saved, increased, and spread in the last 23 years by the use of routine but concentrated wildlife management techniques. This is the trumpeter swan, largest and most magnificent of the wildfowl in the West.

Saving the trumpeter swan took no magic, only hard work, money, luck, and the cooperation of the trumpeter himself. The techniques used were those applied routinely to many other birds. If a species monument exists to game management, it could be appropriately symbolized by the trumpeter swan.

The year 1958 marked the first successful reproduction of transplanted trumpeters on two areas far from their existing population center. Four cygnets were hatched and reared on the Malheur National Wildlife Refuge in southeastern Oregon. Six cygnets were reared at Ruby Lake National Refuge in east-central Nevada. This was a special birthday present for the Malheur Refuge. The 50th anniversary of the founding of the refuge by President Theodore Roosevelt was celebrated by a dedication ceremony on October 25, 1958. The ceremony was held adjacent to Sod House Spring, and eight trumpeters attended, with ringside seats on the spring pond. Their talk was music to the ears of Dr. Ira N. Gabrielsen and other distinguished conservationists who participated in the brief ceremonies.

If all goes well, the trumpeters should increase and spread. It is not likely that they will ever again become abundant, but all nature lovers will be able to hear what is to me the most beautiful sound in

¹ Reprinted by permission from *American Forests*, vol. 65, No. 12, December 1959.

nature—the deep, clarion, French-horn tones of the mighty trumpeter of the West. Why has the trumpeter survived where other remnant species often dwindle to extinction? If we examine the history of the trumpeter, perhaps we may find some answers.

The trumpeter originally ranged throughout a vast area of western North America, breeding from Alaska, Northern Mackenzie and James Bay, south to British Columbia, Montana, Wyoming, Nebraska, and northern Missouri. It wintered in open water areas south to California and the Gulf of Mexico. At the present time there is a small population of about 200 birds in Alaska, and several hundred in western British Columbia and Alberta. The 700 trumpeters in the States of Idaho, Montana, and Wyoming complete the population. They live within a triangle less than 100 miles on each side.

That is trumpeter country, U.S.A. It is within the historic breeding and wintering range of the species. The small size of the occupied habitat makes it very important to increase the breeding range to other areas. Some catastrophe could conceivably wipe out the greater portion of our remaining birds. Who knows what combination of severe winter, disease, drought, or even fallout from a badly aimed ICBM could do to put the United States out of the business of raising trumpeter swans.

Statements of former abundance of trumpeter swans vary, and are further complicated by the difficulty of distinguishing whistling swans from the larger trumpeters in the field. Trumpeters were supposed to be abundant throughout their breeding range. We now know, however, that each breeding pair requires a large territory, large enough to cause doubt of some oldtime estimates of tremendous trumpeter populations. Swans were used for food, shot for the market, and thousands were killed for the breast skins alone. Between 1853 and 1877, the Hudson's Bay Company marketed 17,671 swan skins. How many of these were trumpeters is not known; in fact, it was not until 1831 that the species of whistling and trumpeter swans were differentiated. While swan breast skins were a quality item, they were also used in a later age for such prosaic items as cowboys' coats and, according to a user, "tanned as tough as sheepskin."

Except to the expert, the trumpeter and whistling swans appear identical in the field. Both are large white birds and look about the same on the water and in flight. The major difference is size—any specimen over 55 inches long, weighing over 20 pounds, is probably a trumpeter. There are additional identification aids. Most whistlers have a yellow spot in front of the eye, trumpeters vary in possession of a narrow salmon-red streak or grinning patch on the edge of the mandibles. In 1956 banding operations at Red Rock Lakes, Mont., revealed that this grinning streak was prominent in

98 of 102 birds examined, and 50 to 95 percent obscured in the remaining four.

The surest field characteristic is, of course, the voice of the trumpeter. It can never be mistaken for anything else. A peculiar extra convolution of the windpipe within the trumpeter's breastbone is the final and positive identification. This convolution is also responsible for the trumpeter's clarion voice. Like all swans, the male is called a "cob," the female a "pen," and the young are "cygnets."

We know from records that the trumpeter was widely distributed, but few reports of large numbers of birds have been made by qualified ornithologists, so a reasonable doubt exists that they were ever as numerous as some believe. Records are authentic for distribution, and while trumpeters may not have numbered in the millions, they were found throughout the West. Whether there were many or very many, we know that the trumpeter was intensely persecuted from the time white men entered the country. Trumpeters fly low, near the borders of lakes and marshes, exactly where hunting is easiest. They often wintered on the only open water in cold areas, a habit which tended to concentrate hunting on the species more than on the whistler.

As prairie land was taken up, nesting marshes and potholes were drained. By 1912 E. H. Forbush stated, "The trumpeter has succumbed to incessant persecution in all parts of its range, and its total extinction is now only a matter of years." This seemed true, and by the 1920's the bird had almost vanished. By 1935, there were 73 swans in the United States by actual count, the bulk of these on Red Rock Lakes, Mont., and in Yellowstone Park. If any year was ever critical to a bird, 1935 was the year for the trumpeter. That was the golden year of national wildlife refuge expansion. Large Federal emergency fund appropriations provided money for acquisition and enlargement of many refuges on a scale never since equaled. Red Rock Lakes was one of these. Federal lands were withdrawn for wildlife purposes, private ranches purchased, and the remnants of the trumpeters at last had a home of their own, dedicated solely to their welfare. Forty thousand acres it was, swan breeding and wintering country since the end of the last Ice Age.

Swan had always nested here. Cowboys of the 1880's roped and butchered cygnets to vary a diet of beef and beans. Market hunters and commercial duck clubs had operated. One commercial enterprise near the turn of the century, strangely enough, may have been responsible for perpetuating the trumpeter. The Wetmore family, oldtime ranchers at Red Rock, started catching trumpeter cygnets for sale to zoos and gardens throughout the country. It was a lucrative business for those times, for prices varied from \$50 to \$75 a pair.

Cygnets must have parents, so the hunters, both market and sport, were requested not to shoot adult swans, and, strangely, they complied. This may have been the help needed to preserve the species.

Since establishment of Red Rock Lakes Refuge in 1935, the trumpeter has had the benefits of all applicable wildlife management techniques. Three of the oldest techniques have had a major part in increasing and spreading the birds over a much larger range. These are provision of breeding and feeding areas, protection, and trapping and transplanting. In the course of these activities, the trumpeter became a much-studied bird, and a great deal has been learned about him. Much more remains to be learned, some of it by scientific studies and some in the manner of the old-fashioned naturalist, by just observing.

The best way to discuss some of these findings, as well as the story of the trumpeter and his habitat and management, is to follow through an annual cycle.

Swan country is high; the home triangle is 5,000 and more feet above sea level. Red Rock Lakes Refuge lies in the eastern end of Centennial Valley, Mont., just west of Yellowstone Park. Here the birds have large marshes for breeding and spring-fed lakes with year-round open water for wintering. Conditions are somewhat different in Idaho's Island Park country and in Yellowstone National Park, where swans are also found. Here they nest in small mountain lakes scattered throughout the rolling timbered country; the shallow lakes are good for both swan and moose. Trumpeters winter primarily on the open waters of Henry's Fork of the Snake River, and its larger spring-fed tributaries. A few birds have been successfully transplanted to the National Elk Refuge near Jackson Hole, Wyo. Their habits here are much the same, breeding on marshy lakes and wintering on the open water of the main stem of the Snake River.

Trumpeters start pairing off in February, and late in the month they spend most of their time on snow-covered meadows. Trumpeting increases as the weather becomes warmer, and by mid-March courtship reaches a peak. Shortly after the ice goes out, usually in mid-May, the swans prepare to nest.

Trumpeters are monogamous and probably mate for life, pairing off when 3 years old and breeding at 5 or more. Alvin Misseldine, formerly the Idaho State Conservation Officer at Island Park, says he could almost always tell when a trumpeter had been killed. The surviving mate flew up and down the river for days calling constantly, and would sometimes sit down in a field and starve to death.

Nests are huge structures constructed of cattails or other marsh vegetation, often 4 to 5 feet across. Muskrat houses frequently serve as a base for the nest. Lacking these, a beaver lodge or any other elevation

in the marsh will do. Trumpeters are not particular whether the muskrat houses are active or vacant; both are used. Relatively large nesting territories are needed. In recent years, a staple number of breeding pairs have used Red Rock Lakes. Exactly 44 nests were located in 3 successive years. In Island Park, a pair of trumpeters utilizes an entire lake of 2 to 10 acres in size. One requirement is paramount, that of solitude. Tolerance is very low to human interference; if solitude does not exist, trumpeters will not breed in that place.

Swan eggs are large, and dull white in color. A wide range in egg numbers has been recorded—the usual range given is from 2 to 12. On 2 separate years, nesting studies at Red Rock collected data showing slightly over 5 eggs per nest (50 nests) 1 year, and just under 5 per nest (32 nests) the other year. The eggs were about 110 mm. long and 73 mm. wide. Incubation starts after the last egg is laid and takes about 35 days.

The pair stays together during incubation, although it is believed that the pen does all the incubating. The nest is lined with down, and eggs are covered with down when the pen leaves for her twice-a-day feeding excursions. The cob remains near the nest at all times and warns of any danger. There is usually some protection for the nest; swans prefer a nesting site separated from open water by a strip of bulrush or sedge.

As soon as their down is dry, the cygnets leave the nest and, in a family group, start feeding and exercising near the nest. Distances traveled gradually increase as the young get older. In September flight lessons start, taught and supervised by the parents. Cygnets are usually flying by early October. Family units normally stay together until March of the following year, when the breeding cycle starts anew.

During this nesting and rearing season, all the birds go through a molt. This flightless time at Red Rock Lakes Refuge is the period for capturing the nonbreeders of all ages for transplanting, banding, and scientific studies. Trumpeters are relatively easy to capture at this time. The method developed at Red Rock Refuge is to chase and catch the swimming swan with an airthrust boat. One man drives the boat, another leans over the side and picks the swan from the water by grasping its neck.

Trumpeters, unlike many species of waterfowl, will not fight when captured, but seem to go into a state of semishock. As many as eight swans can be placed on the floor boards of the boat, resting on their backs. They will remain immobile for extended periods, requiring only an occasional touch on the neck to restrain them. When banded, they are returned to the water and have been observed to lie motionless

on their backs for several seconds before righting themselves and swimming away. Capture in this easy fashion does not hurt the birds in any way.

All possible nonbreeding swan are captured and banded at Red Rock Lakes. In 1956 a total of 103 birds were captured and 66 were taken in 1957. The larger number in 1956 represented 65 percent of the nonbreeding birds in the refuge. Thirty percent of the 66 captured in 1957 were repeats of birds banded in previous years. Normal aluminum bands used on other waterfowl have not been successful with swans. Trumpeters wear out bands faster than smaller waterfowl. As a result, stainless-steel locking bands are now in use. Birds in Canada are also extensively banded, and a very few Canadian swan have been recovered in the tristate triangle.

There are two trumpeter census counts each year. One is in August on the breeding areas, and the other in January on the wintering areas. The winter census is part of the nationwide annual waterfowl inventory. Like all wildlife census figures, the census results are not a complete count, but do represent the trend of bird numbers over a period of years; they are essential in evaluating population increase or decrease. The counts have gradually climbed from 73 in 1935 to 735 in 1958, with a general leveling off since 1951. Fluctuations are apparent even in this level plateau of swan numbers, but since the birds have such definite territorial requirements, it is most likely that they are due to flaws in the counting method, rather than changes in bird numbers. This does not imply that the census of trumpeter swans is haphazard or that the methods used are not good. On the contrary, swan counts are checked repeatedly. The enumeration of any wild creature has inherent inaccuracies simply because the count is made of wild creatures, free to hide, move, or appear as they choose. Such counts are among the most valuable wildlife management tools used to indicate the relative changes in wildlife numbers. The results of such a census must be considered as an index number, not as the exact population of the species counted.

Over a long period, it became evident that the refuge was producing about all the trumpeters that would live there, although some spread continues through Island Park as more vacant breeding areas are taken up. It was decided in 1938 to undertake the transplanting program that culminated last year in cygnet rearing in Oregon and Nevada. Over 200 birds have been transplanted, but last year was the first successful breeding. The way has been pointed, and several other areas are being considered as new homes for trumpeters. Transplanted swan are no longer pinioned, but the primary feathers are clipped on one wing to hold them flightless at their new home for a year. After that they are free to move. Low water at Malheur



1 Cygnet.



2. Magnificent adult trumpeters.



1. Trumpeters at Culver Pond.



2. Swans in flight over Culver Pond.



1. Trumpeters were saved from extinction by routine but concentrated management techniques



2. Trumpeters are docile when captured.

Refuge in Oregon has caused trumpeters to seek new habitat in the vicinity.

When the lakes freeze in the fall, trumpeters move to their ice-free winter areas. Some of these are on the refuge and some on the Snake River. A number of swan leave the refuge to winter on the Snake. Food presents a problem and, as the winter progresses, some artificial feeding of grain is done on Red Rock Refuge. Measurements made show that 188 wintering swans consume 2.3 bushels of grain a day. Birds wintering on the Snake River must forage for themselves on river and meadow vegetation. Here they meet a new danger, hunters.

Hunting kill along the Snake River is the only measurable loss of trumpeters. It is a good goose-hunting area, and suitable areas are heavily shot over, especially late in the fall. Fog banks hang over the river much of the time and any large bird seen through the fog is usually fired upon. Trumpeters as well as geese fly up and down the river, and so some swans are killed every fall. This kill varies from 10 to 25 a year. Others are killed and never found. Hunters have no excuse; the snow goose season has been closed for many years in all the counties where trumpeters are found, so no possible reason exists for shooting a white bird. Idaho wardens devote a great deal of their time to swan protection in the area. The Fish and Wildlife Service recently assigned a game management agent to law enforcement in the area during the hunting season. His primary responsibility is to prevent shooting of trumpeter swans. Nesting studies show that less than 16 percent of potential trumpeter cygnets are alive at 10 weeks, and only 10 percent of the potential survive to flight age. Every effort must be made to eliminate hunter kill, for each bird killed is potentially a transplanter and is vitally needed for that purpose.

Frank Belrose fluoroscoped 103 trumpeters on Red Rock Refuge in 1956. These comprised 65 percent of the refuge nonbreeding flock. Although most were young birds, 15 already carried shotgun pellets in their bodies. Man is still the trumpeter's worst enemy, as well as his best friend. Incidentally, weights on these younger birds average 20.98 pounds for males and 17.86 pounds for females.

As trumpeters are transplanted to other areas, the danger of hunter kills will increase. Snow geese are abundant elsewhere, and a closed season on white birds is not practical. Many whistling swans are shot by ignorant hunters each year, and a trumpeter straying from a Federal refuge will be at least as vulnerable as a whistler. Education and good enforcement can reduce but never eliminate the hunting toll on trumpeters. There is some movement of trumpeters from British Columbia to Red Rock. Two trumpeters, wearing bands from British

Columbia were wounded by hunters in Nebraska last year. Some, at least, still migrate, and as trumpeter populations increase, more can be expected to adopt the old species habits. This will increase the hunter toll. It is one facet of trumpeter management that we must expect and plan for.

The American people have every right to be proud of the restoration job they are doing on the trumpeter. Purchase and development of Red Rock Lakes National Wildlife Refuge, transplanting operations, and enforcement of protective laws have increased trumpeter numbers almost tenfold in 23 years. These are simple techniques, but the swans have responded, mainly because of their limited annual range.

The future of the trumpeter is as secure as any small population can be. Much has been done in the past, and as management and fact-finding continues, swans will slowly increase and spread. The sound of a trumpeter's voice can carry 2 miles. It is a sound that could have vanished from our country. For the trumpeter it is still a swan song, not the legendary death song, but the bold trumpet of a species that will be with us into the foreseeable future, the magnificent trumpets in the West.

Reprints of the various articles in this Report may be obtained, as long as the supply lasts, on request addressed to the Editorial and Publications Division, Smithsonian Institution, Washington 25, D.C.

Problems Involved in the Development of Clam Farms¹

By HARRY J. TURNER, JR.

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[With 3 plates]

THE soft-shell clam, *Mya arenaria*, is a commercial mollusk that has played a significant role in the economic and social history of the New England coastal communities and in some instances in other parts of the country. The shells in numerous kitchen middens demonstrate conclusively that the New England Indian tribes depended heavily on this species for food in the relatively barren forest lands of the New England coast. The Plymouth Colony would never have suffered from the disastrous famine of the first winter if the immigrants had known of the clam's existence at the very doorstep of the settlement. Subsequently, other coastal settlements in Maine and Massachusetts managed to survive severe winters by eating clams when the harvest was insufficient. Extensive migrations by inhabitants of inland communities were frequently undertaken in the late winter and early spring to obtain clams to alleviate a starvation diet. Because of their abundance and use as an emergency food, clams were held in low esteem and it is reported that the pious Elder Brewster used most unclerical language when on one occasion he complained that he had nothing but clams to eat.

When the economy of the New England States became organized, the soft clam declined in use as an article of food. However, its commercial importance soon revived with the hand-line trawl fisheries, as the soft clam formed an ideal bait. It opened easily, stayed on the hook well, and its fat body was so enticing that no self-respecting codfish or haddock could resist a nibble. The inhabitants of one small town in Maine did practically nothing else for a number of years but dig, salt, and export clams for bait and also build fishing boats for the larger fishing interests in order to maintain the market for the principal product.

¹ Reprinted by permission from *Oceanus*, vol. 7, No. 1, September 1960.

Few attempts were made to regulate the taking of clams until the beginning of the present century. The supply appeared to be infinite and the demand was so moderate that no one worried about a possible shortage. There was one interesting exception in which one of the States bordering the Chesapeake Bay enacted a regulation, sometime before the Civil War, limiting the number of days a week that a slaveholder could feed clams to his slaves. It is unlikely that this was a humanitarian move, but probably a measure to maintain a continuing supply of food to sustain the large slave population.

NOT LIMITLESS

Toward the end of the last century it became apparent that the soft-clam resources were not limitless, particularly in the New England States. The commercial hook-and-line fishery was at its height, using bait in greater quantities, and "clambakes" became increasingly popular at every occasion from a political rally to a fireman's picnic. Improved methods of transportation provided a means of shipping clams to large centers of population where clam chowder became a required item on the menu of fashionable restaurants featuring shore dinners. As a result the demand began to outstrip the supply and such famous clam-producing localities as Ipswich and Essex had the unpleasant experience of finding their clams disappearing faster than Nature could provide new ones.

At the beginning of the present century, the U.S. Fish Commission and the appropriate State conservation departments of Rhode Island and Massachusetts each employed biologists to investigate the biology of the soft clam with the aim of establishing methods of restoring the supply to what was supposed to be the former abundant level. These scientists investigated the life history, determined the rate of growth, and unanimously agreed that the only solution to the problem was the establishing of privately owned or leased clam farms. Legislation was enacted in Massachusetts which permitted the selectmen or aldermen of coastal towns and cities to grant tracts of intertidal land to individuals for the purpose of clam culture, but the idea was so contrary to the long-established free-fishing tradition that it immediately met with strong opposition. Of the few grants that were made, some failed, and those which turned out to be profitable were soon revoked at the insistence of the independent clam diggers. Discouraged shellfish biologists directed their efforts into other fields, and interest in the soft-clam resources went into a decline. Little was done about the situation until after World War II, although the clam kept increasing in popularity and prices soared to record heights.

Interest was revived with the return of servicemen after the war. Enterprising young men living along the coast, noting the skyrocket-

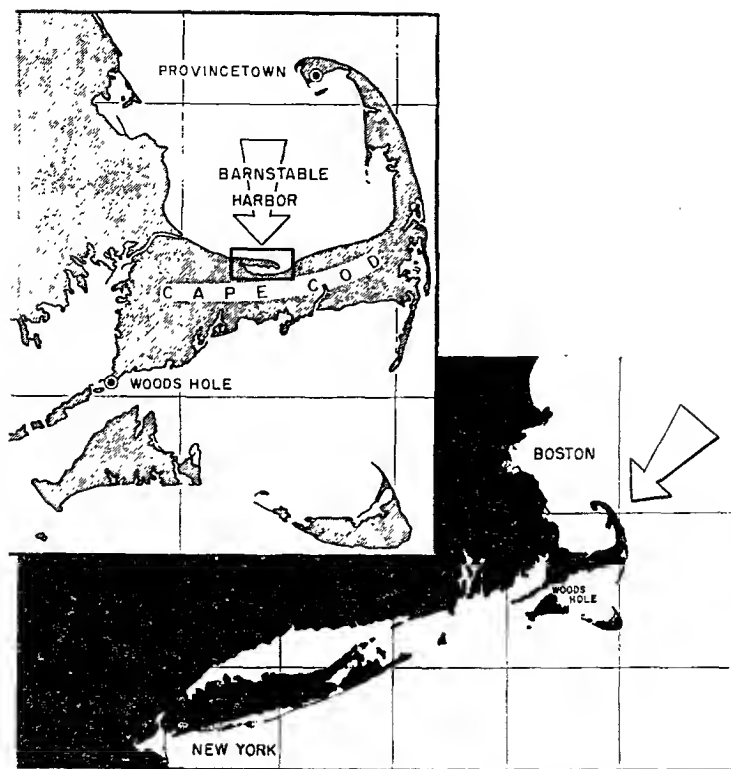


FIGURE 1.—Barnstable Harbor on Cape Cod, Mass., was the scene of the shellfish investigations.

ing prices of clams and the general scarcity in the public digging areas, saw an opportunity to enter into a new profitable venture and applied for clam grants under the old law. They were numerous enough to overcome the opposition, and several potential clam farms sprang into being. In addition, the town of Barnstable, Mass., granted a considerable area to the Woods Hole Oceanographic Institution as an experimental farm and the Institution initiated an extensive investigation into the biology of the soft clam.

Now, to operate a successful farm of any kind it is necessary to know how to stock it with the desired species of animal or plant, provide optimal conditions for survival and growth, and harvest the crop in an economical manner. Several difficulties presented themselves immediately to the clam farmers. The soft clam reproduces by spawning either eggs or sperm directly into the water where fertilization takes place. The eggs are microscopic in size and number in the millions per individual spawner. Each fertilized egg develops into a swimming larva that leads a precarious existence for about 2 weeks, drifting about in the currents. If it survives this period, it

settles to the bottom, loses its swimming organs, and digs into the substratum. It is still microscopic in size at this time and very susceptible to predations by the myriads of creatures that inhabit the bottom. It takes more than a month before it grows big enough to be visible to the naked eye.

This facet of the clam's history immediately posed the problem of how to stock the farm. The farmer could not simply keep a breeding stock on one corner of his grant and expect any result. For all he knew, the offspring of this stock might wind up many miles away after the 2-week free-swimming period. On the other hand, there was just as much chance that a parent stock in some distant cove might provide the offspring to populate his grant. However, he could not depend on such a fortuitous occurrence but had to find a sure way of stocking his grant. This was the first problem that we of the Institution undertook to solve, under contract with the Massachusetts Division of Marine Fisheries.

We knew from some of our plankton studies that clam larvae are always abundant in the water during the summer, even when adults were relatively scarce, because of the enormous numbers of eggs produced by each female. We then made the assumption that the substratum must have some property that either stimulates or discourages settlement at the end of the larval period. This assumption was bolstered by the report of an old fisherman in Barnstable who claimed to have brought about the settlement of large numbers of clams on his grant by resurfacing the area with sediments excavated from a certain marsh bank. We then collected sediments from a wide variety of places and analyzed them for the assortment of grain sizes.

Our preliminary findings indicated that the size assortment of sand grains taken from all places where clams existed in abundance seemed to follow a similar pattern which was measurably different from those taken from places where clams were absent. The materials taken from the marsh bank suggested by the old fisherman fell into this size pattern. We then obtained a boat and a scow and transferred materials from other marsh banks where the assortment of grain sizes did not fall into the pattern. The entire operation was done by hand and we became as adept with a pick and shovel as we were supposed to be with a microscope.

At the end of the summer we surveyed our resurfaced areas and found that they contained clams in what we thought were appreciable numbers, running as high as 300 per square foot, while the surrounding flats remained practically barren. Curiously enough this proved to be the case in all the areas we had resurfaced including the controls. However, the latter plots had become much reduced in size because the strong tidal currents washed the transferred sediments away. The

material from the old fisherman's marsh bank had just the right properties to resist erosion so that the entire plot remained practically intact.

We thought that we had solved the problem of establishing a clam farm and waited for our crop to grow. The clams were still there the following spring and showed such growth that we had hopes for the future. Then we were beset by an invasion of predators. Horseshoe crabs wallowed through the area, cleaning it out at a rate as high as a square foot per crab per day. Boring snails invaded from all sides, each eating as many as three clams per week. To top it all, the green crab population exploded along the New England coast, appearing in such large numbers that they not only worked over our areas but also migrated northeastward through New Hampshire and Maine inflicting serious damage on extensive natural clam beds as far as the Canadian Maritime Provinces. Before the middle of the summer our experimental farm was entirely cleaned out.

12 MILLION HORSESHOE CRABS

We then expanded our investigation to include studies of the life histories of certain predators which were poorly understood at the time. A complete account of our activities in this direction would be much too long for this article, but the results are of scientific interest. We determined that the horseshoe crab takes at least 12 years to mature. Tagging experiments indicated that the horseshoe crabs of Barnstable Harbor traveled many miles and were part of a motile population in Cape Cod Bay containing over a million adults. When the immature members entered the calculation, the total population was determined to run well over 12 million individuals. This clearly indicated the futility of killing a few thousand horseshoe crabs in a single locality such as Barnstable Harbor because of the continuous immigration of others from Cape Cod Bay. The life history of the boring snail was worked out, and it was determined that their swimming larvae remained suspended in the water for as much as a month before settlement. Consequently all efforts to reduce the population in a single locality by attacking the breed stock would be a futile venture. No practical means of handling the predator problem was discovered, but an extensive investigation of the possibility of using toxic substances is now in progress by the U.S. Fish and Wildlife Service and there are indications of promise.

We also continued our studies of the settlement of clams in an attempt to determine the factors that apparently induced the metamorphosing larvae to choose our resurfaced areas. We were puzzled by the fact that marsh-bank materials other than those from the fisherman's favorite bank accomplished this even though their assortment

of sediment sizes did not correspond with the pattern found in natural clam beds. Then the studies of one of our colleagues in the U.S. Fish and Wildlife Service gave us a clue.

Dr. Osgood Smith who was working in Newburyport, Mass., attempted to determine the rate of settlement of clams by placing trays of sand in the flats for short periods of time and then screening out and counting the newly settled baby clams. In the course of his experiments he replaced the newly settled clams in certain trays to determine how fast the population would build up. It so happened that the numbers varied from time to time, sometimes increasing and sometimes diminishing. He suspected predation and attempted to protect an area of flat by staking down a piece of plastic fly screen. After a few weeks, Dr. Smith noticed that the upper surface of the screen became coated with tiny clams with their shells stuck in the openings in such a way that it was clear that they were attempting to burrow down from above. This could only mean one thing. The newly settled clams were not secure in their burrows as had always been supposed, but were continually being washed about by currents and wave action, becoming tangled in any suitable material such as experimental screens, clumps of roots or fibrous seaweed. The migrating clams were so small at this stage and generally so few in numbers that they had escaped observation up to that time. Our resurfaced plots contained a considerable quantity of marsh-grass root fibers which provided ideal places for the entanglement of these migrating clams. Here they became concentrated in the root masses, where they grew big enough to take up their final sessile existence.

The entanglement hypothesis provided a beautiful explanation for the accumulation of clams in the experimental resurfaced areas, but failed to show how dense populations of clams arose under natural conditions. A fortunate circumstance occurred during the month of August one summer, when we were making a survey of the soft-clam resources of Boston Harbor. We came across an area along the Quincy shore where several acres of low-lying flat were so heavily populated with tiny soft clams that they took up just about all the available space on the surface. They were all approximately one-quarter inch long and numbered in tens of thousands per square foot. We surveyed the area carefully and visited it at frequent intervals. By November of the same year the populated area had moved nearer to the shore and the density was reduced to one or more thousands of individuals per square foot. In August of the following year when the clams were a year old and 1 inch long, the population was halfway up the beach and numbered about 400 per square foot. Three years later, when the clams were ready for harvesting, the population occupied essentially the same area but the numbers were reduced to a hundred or so per square foot.



2. During the clam farming experiments at Barnstable Harbor the biologists became as adept in physical labor as they are in the use of microscopes. From left to right: C. L. Wheeler, H. J. Turner, Jr., J. C. Ayers, and Dr. Redfield.



1. Pushing a plow is Dr. Alfred C. Redfield, senior oceanographer emeritus, while working on experimental clam farm. The plowing was done to help seed clams dig in.

PLATE 2

Lieut. P. de Broca—envoy of
French Govt. to U.S. 1862—First Report
Revue Maritime et Coloniale
Trans. by S. F.
U.S. Comm. Fish. 1873-1874

"The people of the United States use clams in a variety of culinary preparations, the most popular of which is, undoubtedly, a kind of soup especially esteemed in Boston.

"In Rhode Island and Massachusetts clams serve as a pretext for fetes of a very peculiar kind, called *clam-bakes*. The following description is taken from a work on natural history published in the United States:

"The clam-bakes which take place every year near Bristol, as well as in several other localities of Rhode Island and Massachusetts, have their origin in an old Indian custom.

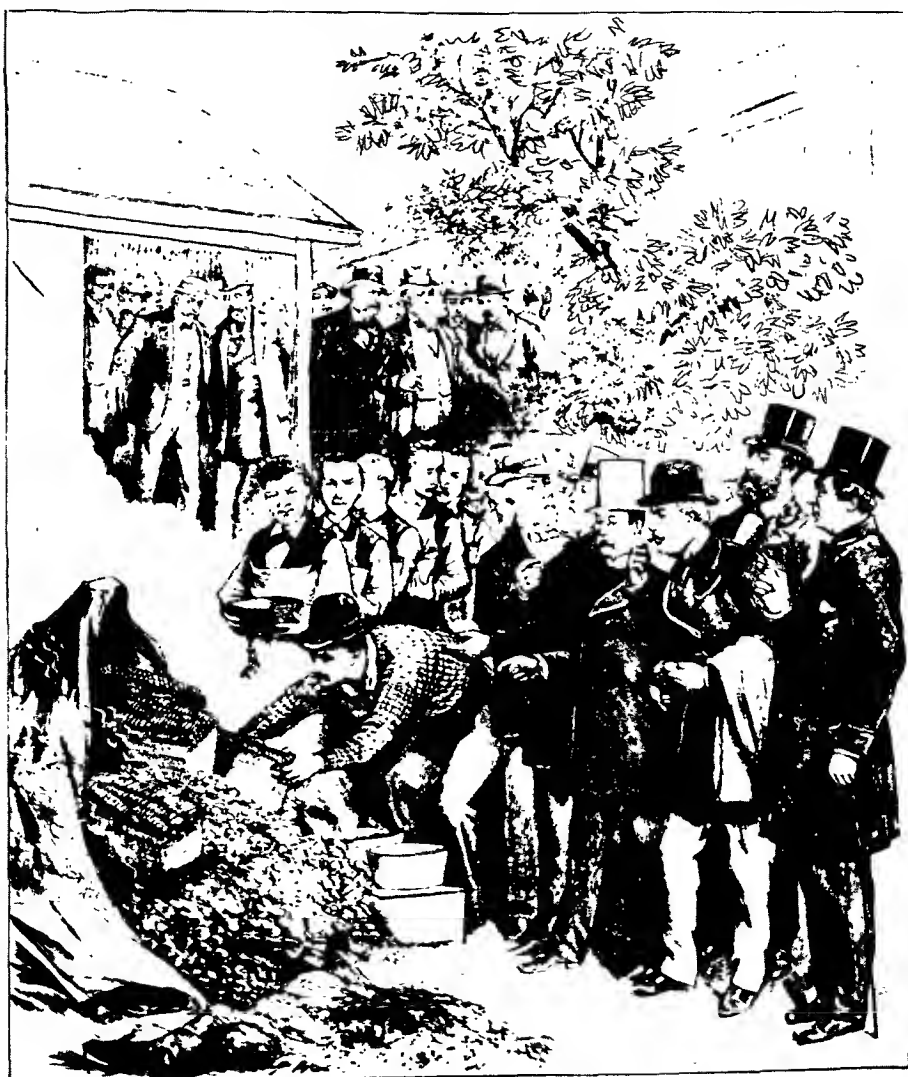
"The aborigines of these States were accustomed to assemble in great numbers every year for a feast consisting of clams and green corn cooked together with sea-weed. The modern clam-bake is an improvement on the old one. A circular hearth or bed is first made in the sand, with large flat stones, upon which a fire is kept up until they are red hot. A layer of sea-weed is then placed upon them, and upon the sea-weed a layer of clams about three inches thick covered by more sea-weed; then follows a layer of green corn in the husk, intermixed with potatoes and other vegetables; then a layer of poultry cooked and seasoned; then more sea-weed; then fish and lobsters, again covered by sea-weed. This arrangement is continued according to the number of persons to take part in the feast, and when the pile is completed, it is covered with a linen cloth to prevent the steam from escaping. When the whole is cooked, each one helps himself without ceremony. These feasts are delicious beyond description, and it is said that no one is ever made ill by them. In former times the most renowned warriors came from afar to take part in them, and now they are attended by persons of the highest social standing, sometimes to the number of several hundreds."

(Courtesy of *Providence Journal*.)

FRANK LESLIE'S ILLUSTRATED NEWSPAPER

NEW YORK, SEPTEMBER 6, 1879.

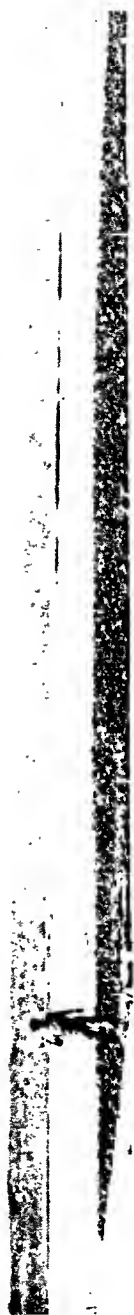
NEW YORK, SEPTEMBER 6, 1879.



(See legend on opposite page.)



1. The "dig" of a horseshoe crab vividly illustrates how a single crab manages to rework a clam flat to find a meal.



2. One-fourth acre of clam flats was resurfaced with marsh grass to help the settling of clam larvae

GEOLOGY INVOLVED

With the help of our colleagues in marine geology we arrived at an explanation involving a hypothesis of "hydrographic concentration" which has been subsequently demonstrated to be correct and also applicable to the formation of concentrations of a number of different marine organisms. Fortunately the geology of the Quincy beach was well understood. The upper beach which consisted of a mixture of coarse sand and pebbles sloped steeply downward nearly to the low-tide mark. Here, it leveled off and the sediments graded through decreasing particle sizes from coarse sand to a very fine silt. The mechanics of the formation of such a beach is as follows: waves striking the shoreline rush up the beach with considerable force, carrying particles as big as large pebbles in the uprush. Some of the water soaks into the beach leaving less water to return in the backwash. As a consequence the backwash runs down the beach with reduced force. The reduction of the force of the backwash causes it to leave the coarser and heavier objects behind, so that the upper parts of the beach remain rocky or pebbly. Lighter particles are transported seaward and deposited according to size as the force of the backwash is lessened. The coarser sand grains are dropped first, forming a flat sandy beach near the low tide while the finer sands and silts remain suspended until they settle out in the relatively quiet waters beyond the level of the lowest low water. The process is repeated during the rise and fall of each tide sloshing materials up and down the beach, separating the particles according to size and density in much the same way that a winnowing machine separates grain from chaff.

These hydrographic forces act the same way on clams. However, clams differ from inanimate objects in that they grow. When they first settle, the clams are microscopic in size and very light. Any disturbance sufficient to stir up the bottom will bring them into suspension and keep them moving until they arrive at some place where conditions are sufficiently quiet for them to resettle along with the silt particles. This, we believe, is what concentrated the clams in incredible numbers in the finer sediments at the lowest part of the beach. The tiny clams sloshed up and down the beach with the rise and fall of the tide, and as they grew they became larger and reacted to the forces of the wash, as if they were coarser sand grains. Thus they tended to settle more shoreward where we found them concentrated at low tide in November. As they grew larger they became more like pebbles and became concentrated on the sloping apron of the beach. By this time they had grown so large that they could dig in deep enough to avoid the disturbance of the surface of the substratum by the waves. Here they remained for 3 years and grew to a size

that was acceptable to the commercial market, providing a period of prosperity for the Quincy clam diggers. A similar occurrence on another beach a few years later was studied in more minute detail by a graduate student at Harvard. His doctoral dissertation confirmed our own findings and proved so many of our assumptions that the principle of "hydrographic concentration" became firmly established as one of the mechanisms of the formation of aggregations of certain bottom animals.

These studies also contributed significantly to an understanding of the enormous magnitude of natural mortality in the marine environment. Biologists concerned with marine fisheries have speculated from time to time as to how many individuals of a generation of any given species survive to maturity, and, for practical purposes have pulled numbers out of a hat ranging from 10 to 90 percent. The mortality rate of the clams in the particular generation under study was well over 95 percent during the first year of their lives, and by the time they were ready for market only a fraction of 1 percent of the original number were still alive. It would be a mistake to claim that these numbers apply to all the creatures that live in the sea, but they may well be applicable to the clams and codfish. Each mature female of these species produces 1 or more million eggs. If all their offspring survived for only a few generations, the ocean level might rise considerably and there would not be room for any other fish!

FURTHER STUDIES

Now after more than 10 years of intensive research it has become clear that the problems associated with the development of clam farming are many and complicated. We have come to the conclusion that these problems cannot be solved by limiting the investigations just to the biology of the clam and some of the obvious predators. Instead, it appears necessary to build up a large background of basic knowledge on the ecology of marine bottom communities. Consequently we have discontinued our investigation of the clam for the time being and with generous support from the National Science Foundation have undertaken a study of environmental influences on the reproductive cycle of a variety of bottom-dwelling organisms.

The Growth of Cotton Fiber Science in the United States

By ARTHUR W. PALMER¹

[With 8 plates]

LITTLE known to the world at large, there has taken place over the last 50 years a development in science of substantial importance to the people of the world who live by the production and distribution of textile fibers and by their manufacture into the fabrics with which the world is clothed. What in effect is a new science has evolved—a science of textile fibers—combining the classic disciplines of physics, chemistry, and biology with a liberal addition of mathematics, complete now with a voluminous literature and professional societies of its own, and lacking only a distinctive name of conventional Greek derivation. From the microscopes, balances, test-tubes, and computers of some hundreds of highly trained research workers have come bold new concepts of fiber structure and a systematic understanding of the behavior of fibers in mass; and parallel with these, a revolutionary new technology that a huge industry has avidly embraced and put to use in the day-by-day task of assaying the quality of the raw materials with which it works. For both the science and the new techniques have evolved in response to an intense need of the industry, of the producer and merchant of the raw material, as well as of the maker of cloth.

Most spectacular, no doubt, of the results of these researches have been those in the field of man-made fibers—in the improvement of the earlier forms such as rayon and acetate fibers of dissolved and reconstituted cellulose, and in the later actual creation of a great number of new chemical forms such as nylon, orlon, dacron, and vinyl, to name but a few. But it is probably in the field of the natural fibers,

¹ U.S. Department of Agriculture, 1920–54 (retired). Head, Cotton Division, Bureau of Agricultural Economics, 1924–36; U.S. Agricultural Commissioner for Europe (Cotton), 1936–39; Head, Division of Foreign Crops and Markets, Office of Foreign Agricultural Relations, 1939–42; Head, Cotton Division, OFAR, 1942–53; Director, Cotton Division, Foreign Agricultural Service through 1954; Chairman, Interdepartmental Cotton Committee for the European Recovery Program (Marshall plan), 1947–48; General Secretary, International Cotton Advisory Committee, 1946–54.

and particularly of cotton, that the most extensive changes have been made in the methods and practices of the industry and trade, and these are enough to warrant an accounting of the work on cotton alone.

Cotton, indeed, in the universality of its production and use and in the numbers of human beings to which it gives employment, holds a place unique among the fibers. Grown in some 60 or more countries, it is utilized throughout the world more generally, in far greater quantity, and in a far wider variety of products than any other. In the United States alone, to produce the crop, gin it, assemble and merchandise it, and to warehouse and transport it as raw material gives a livelihood, it is estimated, to more than 5 million people. To spin, weave and knit, finish and fashion into apparel that part of the crop that Americans alone consume supports probably 5 millions more. Quality enters importantly in almost every operation and business transaction throughout this entire chain, from the propagation of the planting seed to the selection of the bales fed into the manufacturers' machines, and indeed to the adjustment of those machines, for variation in the quality of cotton affects both its cash value and its suitability for any given use. Yet cotton is after all a strangely inscrutable commodity and gives up its secrets reluctantly.

The difficulty of understanding cotton quality grows out of its own complexity. A single pound—no more than can be stuffed into a two-quart fruit jar—comprises 100 million or so fibers, each a single elongated cell from the outer coat of a cotton seed, and each as individual in its own peculiar characteristics as a human being. A normal fiber forms first as a thin-walled hollow tube, sometimes tapered from base to tip, within which a cylindrical layer of cellulose is deposited daily, roughly like the rings formed annually in the trunk of a tree. In the course of time the partially filled tube matures and the depositing of cellulose ceases. At this stage the cylinder collapses about its hollow interior or lumen into a ribbonlike thing, much like a collapsed inner tube of an automobile tire, and twists itself in spirals around its own axis. But even though they grow upon the same plant or spring from the same seed, not all fibers are normal. Some never mature; nor, if normal, do they all develop alike. Some are strong as steel; others are weak and brittle; some are harsh, others are soft; some are coarse, some are fine; some are definitely tapered, in others the walls are more nearly uniform and parallel throughout most of their length; some are brilliantly white, others are pearly white, or discolored or stained.

Every one of these characteristics affects in some obscure way the behavior of the cotton in spinning or the quality of the spun and woven textile, and so is a factor in the quality of the raw cotton itself. Thus, if cotton fibers in a bale were uniform like nails in a

keg, that is to say if they were uniformly long or short, or thick-walled or thin-walled, appraising the quality of the cotton in a bale might be fairly simple. But this is never the case. Always the mass of fiber is a conglomerate of many, if not all, of these diverse properties, commingled in a myriad of permutations and combinations. The quality of the mass is governed by the proportions which fibers of these different characteristics are of the whole, by the influence which each proportion exerts upon the properties of the manufactured textile, and by the physical interaction of fibers of one type upon those of other types. In spite of all efforts to achieve uniformity in production, cotton actually comes to market in an incredibly wide range and diversity of qualities, which have to be accurately identified and described.

How tremendous, percentagewise, are the differences in and between individual cotton fibers, invisible though most of them are to the eye and impalpable to the touch, may be appreciated from the following observations, reported by Dr. Robert W. Webb of the United States Department of Agriculture to the National Cotton Congress at Waco, Tex., in 1940:

The overall cross section of cotton fibers varies from as low as 26 square microns to as high as 1,164 square microns, or a range based on the minimum of 4,377 percent.

The range of wall thickness in cross section varies from as little as 0.35 micron to as high as 15.5 microns, or a range of 4,328 percent.

Lumen width varies at least from 0.35 to 12 microns, or 3,328 percent.

The major axis of the lumen varies from as low as 0.5 micron to as much as 40 microns, or 7,900 percent.

The cross-sectional shapes of cotton fibers vary almost as much as the size and wall thickness.

The soundness of the cellulose varies greatly as indicated by fluidities ranging from 2 to 50 rhes (2,400 percent), copper number from 0.2 to 1.5 (650 percent), and alkali solubility from 2 to 7 percent (250 percent).

Wax content varies from 0.5 to 10.0, or a range of 1,900 percent.

Of fibers in the mass, Dr. Webb added:

The proportion of thin-walled fibers varies from as low as 6 percent to as high as 77 percent, or a range of 1,183 percent.

The color ranges from the most delicate of creamy whites to the deepest sort of yellow stain, chroma units being as low as 0.6 and as high as 3.20, or a range of 433 percent.

Fiber bundle strength varies from 40,000 lbs. per square inch (of cross section) to as high as 120,000 lbs. per square inch, or a range of 200 percent. Strength values have been found to be as low as zero in some deteriorated cottons.

Moreover, every ounce of raw cotton is composed of not one or two or several different fiber lengths but, in fact, a multitude of fiber lengths intermingled in various proportions, the length and length-variability factors of which appreciably affect the utilities and values of different cottons. Even the fibers from a single seed show a char-

acteristic pattern of fiber length distribution. The coefficient of fiber length variability for the array of cotton fibers so removed from the seed by hand, however, is exceedingly small and its value may go as low as 7 to 10 percent. Ginned lint possessing an exceptionally high degree of fiber length uniformity has been observed to give a coefficient of length variability as low as 18 percent. Such uniformity, however, occurs only rarely. For the general run of commercially ginned lint appearing in domestic and foreign markets, below 27 percent is considered a low length variability; 27 to 34 percent, average; and above 34 percent, high. In the case of so-called "irregular, weak, and wasty" cottons, which generally result from adverse growth conditions or premature opening of the bolls by frost and subsequent breakage of the predominant thin-walled fibers during ginning, the coefficient of fiber length variability may go as high as 50 or 60 percent, or even higher.

Thus, with fibers in most short staple cottons varying in length in diverse proportions from less than $\frac{1}{16}$ inch to 1 inch or more, with fibers in long-staple cottons varying from less than $\frac{1}{16}$ inch to as much as 2 inches, and with fibers varying from less than $\frac{1}{16}$ inch to more than 2 inches in extra long-staple cottons such as Sea Island growths, the length factors and effects bound up in cotton quality become manifold. Moreover, the fiber walls are collapsed in greater or less degree throughout the fiber length, lateral convolutions vary from almost none to 500 or more per fiber, and the shapes and areas of the cross section of the fiber are usually variable throughout its length.

Even more amazing, perhaps, is the fact that the fiber length may be as much as 4,000 or more times its width. To illustrate, if a 1-inch cotton fiber with about average cross-sectional features were magnified to a width of 1 inch, its proportionate length equally magnified would be about 100 feet. And, if a typical 2-inch Sea Island fiber were magnified to a width of 1 inch, its proportionate length would appear to be about 400 feet. Incredible as these figures may seem, they illustrate the extreme and unusual types of ratios with which textile processing machines must deal when converting raw cotton fibers into spun yarns.

And, as if this were not complexity enough, cotton fibers attract and give off moisture in continuous adjustment and readjustment to changes in atmospheric humidity, writhing and curling in the process, and varying their apparent length and the tenacity with which they cling, one to the others, when spun into yarns.

Over the thousands of years that cotton has been spun and woven for man's use, a certain expertness was developed in selecting out and describing cottons which possess in the aggregate, or mass, similar quality characteristics; and it is a tribute to the genius of earlier

generations that, by this rather simple—and sometimes mystery-shrouded—process known as “classing,” the more skillful manufacturers have been able generally to select the cottons needed to produce their customary fabrics, some of them of amazingly fine quality. But, classing is a human hand-and-eye operation and at its best leaves much to be desired. In the normal order of things the process cannot be exact; cotton quality by its nature is too complex, too intricate and too involved with variations of its individual fibers and of its combinations of individual fibers to lend itself fully to simple methods of measurement or evaluation. Too often, consequently, the accuracy of classing or the reliability of quality descriptions become the subject of dispute. Too often, as manufacturers of the newer industrial textiles have had to meet buyers’ rigid specifications, classing has failed to assure them the right cotton for their exacting work. Too often the seed-breeder, seeking to set a goal for the improvement of his strains, has been left groping for guidance.

Half a century ago studies were begun in this country to establish fixed standards of cotton grades and staples which, under government authentication, were intended to be universally accepted and applied throughout the industry. In a series of legislative enactments between 1914 and 1923, quality standardization and identification were made a responsibility, first of the Bureau of Markets and then of its successor agency, the Bureau of Agricultural Economics. The first official standards were established in 1914. In 1923, the official United States grade standards were accepted throughout the world as Universal Standards for American cotton. Over the years much has been accomplished by means of these official standards in unifying and stabilizing the concepts of quality employed by cotton classers. But standards created by classers have all the shortcomings of the classing art itself, and even the stamp of the Government of the United States has not always proved a sufficient *fiat* to protect them from a challenge of their uniformity or of their constancy—two of the basic requisites of a standard of any kind. This was a problem that began to vex and embarrass the Department almost from the time the preparation of standards was first undertaken. Some early researches had been started in an effort to find solid ground—some definite relationships to known and accepted constants—on which firm specifications of standard qualities could be rested, but these had been abandoned when they appeared to be bogging down in a morass of confusing and irreconcilable results. Controlled spinning tests had previously been undertaken under direction of such masters as Fred Taylor and Drayton Earle, followed by the late W. G. Blair and H. H. Willis, and with the indispensable cooperation of North Carolina State College and Clemson College had progressed well. But spin-

ning tests tell only what a particular cotton can do—not what it is or why it does it.

Such was the state of things in 1927 when the Department, more than ever beset with its problems of standardizing quality descriptions and aware that in England and continental Europe scientific studies of fibers were already under way, determined to make a fresh attempt to get to the fundamentals of cotton quality. In its search for a leader of the new attack, it fixed its sights on a promising young scientist, Dr. Robert W. Webb, who had been steeped in plant science by an inspirational teacher, Dr. Henry W. Barre, at Clemson Agricultural College, had gone on to his doctorate in plant physiology and pathology at Washington University in St. Louis, under a world-renowned biologist, the late Dr. Benjamin Duggar, and then had prepared himself further by postdoctoral study at the University of Wisconsin. Although it necessitated a radical change in the plans for his professional career, Dr. Webb, after mature deliberation and on the advice of his academic sponsors, agreed to shoulder responsibility for the contemplated project. This may be said to mark the starting point in the United States of the advance that was to accelerate and broaden into the wide movement that it is today. For the next dozen or more years, Dr. Webb was at its head; the record of progress in that period was largely written by him and his associates in the Department of Agriculture.

Two years went into Webb's quiet preparation—reviewing and digesting the scientific literature of this country and Europe, meeting and talking with cotton manufacturers and merchants, and with geneticists and breeders about their basic quality problems. Soon it became apparent that the task Webb had undertaken was too far reaching, too difficult to be solved by any one man alone, or even by a few; and that, if ever the secrets of cotton quality were to be discovered, a group of finely coordinated workers of specialized but varied talents—an orchestra of research workers—would be needed to do it. Accordingly he set about programing the work in a series of manageable projects, and proceeded to recruit a staff of enthusiastic young physicists, chemists, cytologists, colorists, microscopists, and mathematical analysts, including a radiologist. With their counsel he planned his laboratory and selected the most advanced apparatus obtainable with which to equip it.

But not in the arsenal of science were all the weapons needed for the attack. Clearly, one of the first requirements was an instrument by which the individual fibers in the cotton mass could be separated out and arranged in orderly length arrays for analysis and measurement. Numerous attempts to devise such an instrument had been made earlier, but none had been free of certain objectionable limita-

tions. Webb studied them all and then came up with his own design of a fairly simple instrument, which he induced a commercial manufacturer of scientific apparatus, Alfred Suter, to construct. The result was all that was hoped for; it did the work and did it right. Webb was granted a patent on the invention, which he immediately dedicated to public use; and then, in the hope that it would help Suter to sell the instrument to others, insisted with characteristic generosity that it be called the Suter-Webb Duplex Fiber Sorter.

In the view of many of Webb's contemporaries, the Suter-Webb Sorter was the key that opened the gateway to a whole vast field that awaited exploration. Primarily it afforded means of visualizing and evaluating the length, uniformity, and distribution of fiber lengths present in the cotton mass. More than that, it permitted incisive studies to be undertaken of the differential characteristics of the longer, median, and shorter fibers in a single cotton. From this point onward, microscopic and ultramicroscopic as well as physical and chemical analysis took on new meaning; and it began to be possible to trace more certainly the relationships of some of the properties of the fibers through to the properties of the textile products. As the late Thomas Kearney, famed for his introduction of Egyptian cottons to Southwestern irrigated agriculture and for evolving the Pima variety, was to write Webb in 1956 after reading a review of the progress of cotton fiber science up to that time:

You have every reason to be proud of your part in these investigations, which have revolutionized all phases of the cotton industry from breeding to marketing. The Suter-Webb (I think it should be Webb-Suter) Sorter, alone, was an amazing achievement.

Subsequent inventions have made it possible to obtain similar results in shorter time, but for maximum precision, the Suter-Webb Sorter remains to this day the ultimate instrument.

Webb's staff also began to contribute important new ideas in research tools and processes. Parallel with his own invention of the cotton fiber length sorter came the development of a radically new method for measuring the strength of cotton fibers in mass, involving the use of a device invented by Dr. E. E. Chandler, which was to be known as the Chandler Strength-Tester. Similarly, a penetrating study of the subtle and elusive variations of color in cotton was being carried forward by Miss Dorothy Nickerson and this work, too, was bringing forth new and advanced apparatus of highly ingenious and specialized design for fine color identification and measurement.

Mrs. Wanda K. Farr, an eminent cytologist, in an exploration of the molecular structure of the cotton fiber-cell was simultaneously applying advanced microscopic and radiographic techniques to the study of widely varied types of cotton representing successive stages

of growth in materials of controlled production. The striking nature of her findings and her brilliant and lucid presentations soon caught the attention not only of the community of cotton scientists but also of important elements in the rayon industry, which forthwith opened to her an even more alluring research opportunity. Nevertheless, in her relatively brief association with Webb's group, Mrs. Farr stirred the interest of other workers who entered the field and, following her lead in the use of X-ray apparatus, pursued further rewarding studies of the basic wall structure of cotton fibers.

Although the program of Webb's fiber laboratory was conceived in true scientific modesty, and premature publication was sternly discouraged, it was not long before paths were being worn to his door from several directions. Designed originally, as it was, to enable the grade and staple standards to be placed on a foundation of firm and incontrovertible specifications, the work began to fire the imagination of thoughtful people throughout the entire range of the industry and invitations to discuss this work publicly came with increasing frequency.

The intensity of public interest that had by this time developed is well illustrated by a letter from Dr. R. Y. Winters, Director of the North Carolina Experiment Station, dated April 5, 1935, in which he said:

I wish you to know how much we appreciate the conference with Drs. Webb and Farr here on April 3. The conference was promoted by the Textile School, the School of Science and Business, and the School of Agriculture of the College. In arranging the conference, we had hoped to accomplish some very definite objectives . . . We wished to bring to research workers and teachers in technical subjects a fundamental approach to problems common to us all . . . The advanced students in textiles and agriculture might get a broader insight into related problems with which they must deal in the future . . . So far as the performance of Dr. Webb and Dr. Farr was concerned, our objectives were more than realized. Dr. Webb gave a splendid presentation of the fiber work. The slides were clear and substantiated his splendid discussion . . . Voluntary expressions from chemists, physicists, textile specialists, botanists, physiologists, and agronomists in attendance indicate that they were all favorably impressed. After the two conferences, I felt like shouting from the housetops that work like this will determine national security and supremacy . . .

Dr. Winters' ringing words brought welcome encouragement at a time when the basic soundness of the pioneer program was yet to be demonstrated. Equally helpful was the support of other institutional leaders, notably Dr. Henry W. Barre, Director of the South Carolina Agricultural Experiment Station, whose unqualified endorsement did much to assure its acceptance in agriculture's educational circles throughout the South. Director Barre had indeed given sympathetic counsel from the beginning, and, like Dr. Winters, had placed essential laboratory, greenhouse, and field-plot facilities at the disposition

of Mrs. Farr. Similar valuable help came from the late Dr. William Crocker, then Director of the Boyce Thompson Institute for Plant Research at Yonkers, N.Y.; and for the early studies of cellulose structure Prof. George L. Clark made available the X-ray equipment of the Chemistry Department of the University of Illinois.

Among the first of the other fields in which fiber analysis was recognized as having application was ginning. Much injury to the quality of America's cotton crop was known to result from faulty ginning in some of the more than 14,500 cotton gins operating in the country at that time; and in certain quarters a movement had been proposed to put ginning under Federal regulation. The Department of Agriculture did not, however, accept this proposal, believing that technical knowledge was inadequate for a satisfactory inspection service and that, in any case, the remedy lay in another direction.

The ginning question was resolved by the building in 1930 at Stoneville, Miss., of the National Cotton Ginning Laboratory, the world's first of its kind, made possible by a generous gift of land from the State of Mississippi. Here, in a magnificently designed plant, complete with its own fiber laboratory, was developed one of the finest examples of teamwork in research ever to be witnessed in this country. In double harness an engineering staff, under the dynamic leadership of the late Samuel H. McCrory and Charles A. Bennett, pooled its forces with those of Webb's fiber analysts under Leo Gerdes in a broad program of ginning research and education. Before long, Stoneville became a Mecca for ginners from all parts of the cotton belt, while few conventions of ginners took place without Bennett or Gerdes, or both, speaking from the rostrum. Fiber analysis had opened the way for a whole new understanding of the ginning process.

Another group soon to seek out Webb's laboratory was that of the textile manufacturers. It happened in 1931 that the crop of that year turned out to be a great disappointment to spinners. Manufacturers repeatedly found themselves frustrated in trying to meet buyers' specifications, and confronted with the return of goods rejected on delivery for deficient quality. A progressive but distraught manufacturer, Eugene Gwaltney, bound for New York to attend a meeting of the Textile Committee, D-13, of the American Society for Testing Materials, stopped in Washington and in search of help sought out Webb for a day-long interview. So impressed was he that he arranged an eleventh-hour invitation from the Society and prevailed upon Webb to accompany him to the meeting. The meeting time had long been scheduled full, but Webb was asked to give an impromptu talk at the banquet, following the feature speaker. Although this was the last event of the meeting, and the audience had listened to a long series of programed papers, the group was electrified and

stayed on into the morning. Soon afterward, a party of the cotton department heads of the four major tire manufacturers arrived in Washington to petition the Department of Agriculture to afford them a testing service employing Webb's new processes. Conventional classing methods of quality determination, they said, were not getting them the cottons they needed.

Through the American Society for Testing Materials—industry's own official organization for the approval and adoption of uniform techniques for the new testing of industrial raw materials—industry's interest was still further increased. On Webb's suggestion the Society organized a Raw Cotton Section, and he was pressed to accept the section chairmanship. Webb at first demurred, believing it best that the Committee keep itself in position to evaluate his work with complete objectivity. But, as time passed the pressure increased, and in 1934 Webb finally yielded. He held the office through 9 productive years, finally retiring at his own request in a shower of encomiums for the service he had given and of regrets for his leaving it. It was during Webb's regime, it may be added, that the first standard test methods for the measurement of various cotton fiber properties, including specifications and tolerances, were put on the books of the American Society for Testing Materials. Moreover, practically all the basic fiber test methods that he sponsored many years ago remain on the ASTM books today, though they appear now in somewhat revised and improved form, as a result of further developments in knowledge, techniques, and skills since their original adoption.

If ginners and manufacturers were interested, commercial seed-breeders and experimental geneticists were enthusiastic. A number of them, almost from the beginning, were frequent visitors to Webb's laboratory, eagerly following the progress being made and stimulating the work with their encouragement. In 1933, when a policy of retrenchment was ordered in keeping with a sweeping reduction in total governmental expenditures, these people voluntarily came forward to demand that the work be not reduced but expanded and intensified.

Confidence in the soundness of Webb's program was reinforced at an early stage by two of his own notable achievements, which are now regarded as classics in fiber science. First, in seeking to solve the riddle of the relationship of fiber fineness to the strength of yarns during the early 1930's, Webb had his assistants in his spinning laboratory at Clemson College mechanically cut extra long and very fine Sea Island cotton to lengths comparable with bread-and-butter upland cottons, and to commingle them in varying length proportions, after which the mixtures were spun into yarns. The approach was original and unique; the results were sensational. Yarns spun from

the cut Sea Island mixtures were found to be approximately 50 percent stronger than comparable yarns spun from upland cottons of similar natural lengths but characteristically of appreciably coarser fibers. These results were later to be confirmed in experiments with a most extraordinary natural cotton, the native Hopi found in the mountains of southern Arizona. This extremely fine and thin-walled but very short-stapled cotton, obtained through the cooperation of the late Thomas Kearney, performed amazingly well in the spinning process and produced a yarn of incredibly high strength, staple length considered. With the evidence thus gained of the importance of fiber fineness as an element of cotton quality—never before thoroughly understood or appreciated in connection with upland cottons—geneticists and cotton-seed breeders were enabled to set themselves an invaluable new target for their improvement aims.

On the principle that frequent reexamination of methods and progress are essential to the health and success of any pioneer research undertaking, Webb and his project leaders regularly subjected their work to strict appraisal. In 1935 it became possible to do so with understanding broadened through personal contact with their opposite numbers in England and continental Europe. Attending the International Cotton Congress of that year in Rome as informal observers for the United States, Webb and Malcolm Campbell, leader of cooperative spinning tests at Clemson College, were given opportunity to meet a number of scientists in the field, and were offered assistance in meeting others by several of the leaders of the European cotton industry. Five following weeks were then given to visits to the principal research and testing laboratories in six countries abroad, where technical problems were discussed and views exchanged with research leaders and laboratory workers, most of whom had theretofore been known only impersonally through their scientific publications. Thus, not only was the way opened for subsequent valuable interchanges of correspondence and data, but Webb and Campbell were able also to return home more than ever convinced of the soundness of their program and of the need and wisdom of accelerating it.

Not long in coming was the first large-scale application of the new methods of fiber quality analysis. Over many years thoughtful students of cotton agronomy, concerned with the problems of efficient production and with the need for reducing variation in the quality of the crop, had hoped for a time when it might be known with some assurance what were the influences of soil and climate upon the characteristics of any known variety, and what were the varietal characteristics of cottons best suited to the particular conditions of soil and climate of the many diverse local areas of growth. In 1935 leaders in the U.S. Department of Agriculture and directors of cotton

State experiment stations, viewing the progress that Webb and his associates had by that time made, concluded that the new techniques and methods were then sufficiently developed to permit a thoroughgoing and comprehensive study of the principal varieties of cotton in production from the Atlantic across the country to the Pacific.

Thus was conceived and planned the Regional Variety Study of 1935-6-7, a huge program of coordinated agronomic and technological effort which was to lay a foundation of data theretofore unavailable, on which varietal improvement and simplification, district by district, would be predicated for many years to come. Sixteen varieties of cotton, selected for their purity and importance in production, were grown experimentally in each of the 3 years at each of 14 locations in the rain-watered portion of the cotton belt, each variety being represented by 8 replications at each station. In 1937 an additional station in Texas was included, and seven selected varieties were grown at four stations in the irrigated valleys of the Southwest. A total of some 6,000 experimental lots of ginned lint resulted. The growing, harvesting, and ginning of these cottons, and their agronomic evaluations, were the work of Federal and State specialists under the direction of Dr. Henry W. Barre, then Head of the Division of Cotton and Other Fiber Crops and Diseases in the old Bureau of Plant Industry. It was the part of Webb and his people to make the laboratory determinations of fiber length and length uniformity, fineness, strength, maturity, nep content, and the X-ray patterns of crystalline cellulose structure. The total material assembled considerably exceeded the laboratory capacity then existing, but complete fiber and spinning tests were made of samples representing the 16 varieties grown in 2 replications in the 3 crop years at 8 locations selected from the national range, with the inclusion of some samples taken from other stations. So was accumulated a massive and invaluable body of precise data, the interrelations of which have been the subject of continuing analysis for a quarter of a century, and which constituted the statistical staging ground from which have come the phenomenal improvements in the quality of the American cotton crop within that period. For historical purposes, moreover, these data will long be of interest as the first dependable bench mark of their kind from which progress in the future can be measured.

Soon followed another achievement by Webb, aided by his longtime professional associate, Howard Richardson, which doubtless more than any other served to put fiber science on a firm foundation in the United States if not indeed over the world. This was the discovery in the late 1930's of a high positive relationship between strength in raw cotton fibers and strength in yarns. Earlier investigators had failed repeatedly in their efforts to find and evaluate such a relation-

ship. Researchers in Europe had been able at best to trace only a low degree of positive correlation, and not infrequently their results indicated actually a negative correlation. These disturbing results, so obviously contrary to all reasonable assumptions, were apparently caused by the use of data accumulated from the breaking of single fibers individually without regard to their cross-sectional size. Webb and Richardson accomplished their significant breakthrough by using data on the aggregated strength of fibers in a bundle, broken on the Chandler Strength-Tester—a method originated in his own laboratory. Thus a basis was laid for the development of a large number of equations for predicting yarn quality from an analysis of the raw material.

Such was the beginning. As time went on, the appeal of the tire makers for a "service" was taken up and reinforced by the breeders. Their ideas were crystallized in 1940 in a letter from the founder and president of the National Cotton Council, the late Oscar Johnston, to the Secretary of Agriculture in which he said:

At present there are a few cotton breeders and growers who have done something about improving fiber and spinning qualities. Under the stimulus of the work done by Dr. R. W. Webb, . . . these breeders have translated what was originally a few theories into an action program. When Dr. Webb developed methods for their measurement he laid the foundation for actually improving the quality of American cotton.

. . . Cotton breeders are now selecting and breeding the strains of cotton that have unusual strength, very desirable fiber fineness, and some of the new strains are more uniform than others previously produced in the United States. When these cottons are spun into threads, cords and fabrics they have made outstanding records in the trade for which they were produced, notably the tire trade. Enough of this fiber testing and spinning has been done to prove the soundness of Dr. Webb's original assumptions.

No one acquainted with this work refutes the statement that it is at this time the most hopeful endeavor in the whole field of cotton improvement. It holds more potentialities for actually improving American cotton than anything else that has been done or is being done.

D. Howard Doane, founder of the Doane Agricultural Service, wrote Webb in 1940 in these words:

I cannot tell you how many people of prominence are saying that this work which you so modestly started a few years ago constitutes the most promising picture in the whole field of cotton advancement.

By special authorization from Congress, the breeders and the manufacturers got the service they wanted, at least within the limits that research up to that time would justify. On August 27, 1941, the Department of Agriculture announced in the Federal Register a schedule of fees for which, subject to the limitations of its capacity, it would test cottons for length, strength, and fineness in its fiber laboratories, of which by that time there were four, located respectively at Wash-

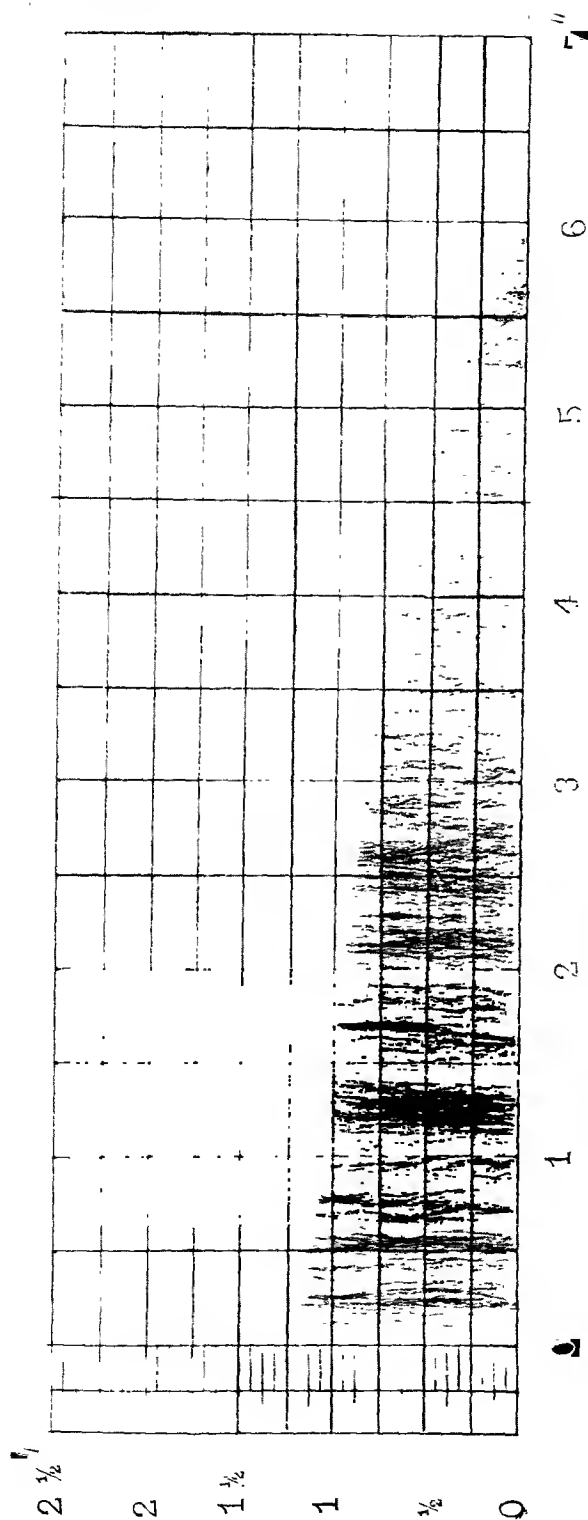
ington, Clemson in South Carolina, Stoneville in Mississippi, and College Station in Texas.

The response of the cotton seed breeders was hardly less than jubilant. The late Dr. George Wilds, then President and Chief Geneticist of the Coker Pedigreed Seed Company, addressed the South Carolina Chemurgic Conference at Columbia in 1942 on the advantages of the new service and took occasion to pay special tribute to Dr. Webb. The studies up to that time, Dr. Wilds said, illustrate immediate possibilities of great improvement and he added:

This service gives us an opportunity to breed cottons that will reach new horizons in quality, but only if we avail ourselves of this opportunity. This is a distinct challenge to the commercial breeder, for it is to him that most cotton growers look for improved seed. This service can be of inestimable value, and by using it, quality can be reflected into the American crop quicker than any other way.

That this was indeed a sincere and genuine statement is attested by the character of the speaker and by the fact later reported by his successor, Robert Coker, that his company had "invested" no less than \$75,000 in fees paid to the laboratory at Clemson College for evaluation of its improved strains. But the new service was only an offshoot—a practical application of results—of the research up to that time. The program of fiber research that made this service possible was still to be amplified and intensified, not in one laboratory alone but in scores of others as well.

With the wide appeal of the work and its application to diverse segments of the industry, it was inevitable that organizational problems should arise. In research aimed at improvement of marketing procedure and of the grade and staple-length standards, the Bureau of Agricultural Economics was well within its jurisdiction. But research aimed at crop improvement was logically a function of production agencies, most specifically at that time of the Bureau of Plant Industry, which now faced a burgeoning need to apply the new methods of fiber analysis in its own work. For a time this situation was bridged by a cooperative arrangement, under which Webb's laboratory undertook to make its facilities and skills available to the Plant Industry program in return for certain contributions of salaries and material. Meanwhile, however, came the establishment in the Bureau of Chemistry of four great regional research laboratories, the purpose of which was to find means of increasing the use of surplus agricultural products as raw materials of industry. Thus a new and direct link with the cotton industry was created in which fiber analysis was a prime essential. Webb was called upon to give up some of the key members of his staff to form the nucleus of the fiber group of the Southern Regional Laboratory at New Orleans. Then, in the course



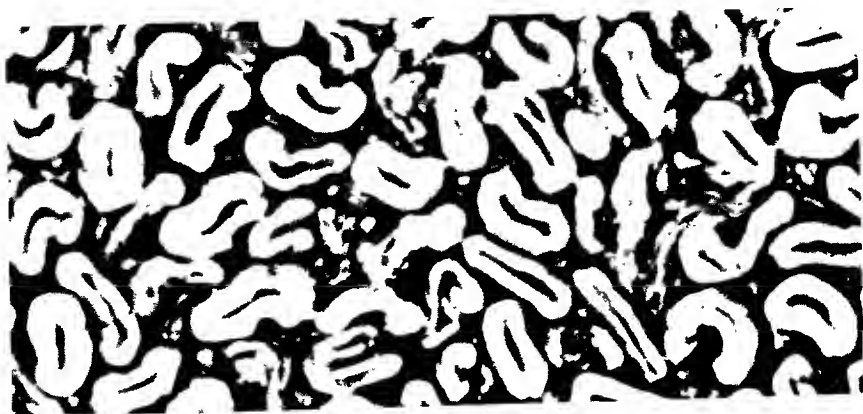
A typical fiber length array illustrating the general pattern of fiber length distribution found in any raw cotton. The longer the staple length of cotton the greater is its range of fiber lengths. The coefficients of length variability fluctuate appreciably for different samples of cotton as influenced by the presence of varying proportions of the respective fiber length groups. A C I A. of 27-34 percent is considered average variability for raw cotton that has been mechanically ginned.



Composite photomicrograph of longitudinal views of mature cotton fibers of different botanical growths selected to represent a range in fineness: Specimen *a* is a fine fiber from Sea Island cotton *Gossypium barbadense*, staple length 1-3.4 inches; *c* is a very coarse fiber of the variety Gayo Hill from Asian cotton *G. Verbaecum*, staple length about 5.8 inch, and *b* is a fiber of intermediate fineness between *a* and *c* from American upland cotton *G. hirsutum*, staple length 1-3.8 inches. Magnification in all cases X 475.



1.



2.

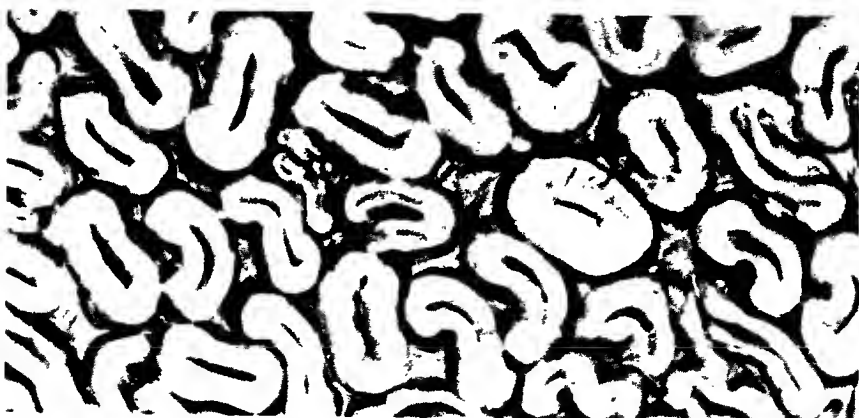


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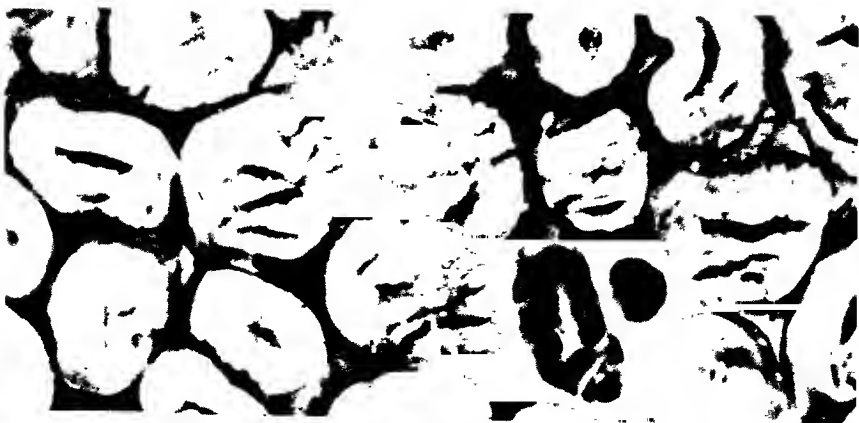
Photomicrographs of cross sections of cotton fibers selected to show a range of geometrical fineness and shapes: 1, Very fine, Sea Island; 2, fine American upland; 3, medium, American upland. Magnification in all cases X 760. (See also tables 1 and 3.)



1.



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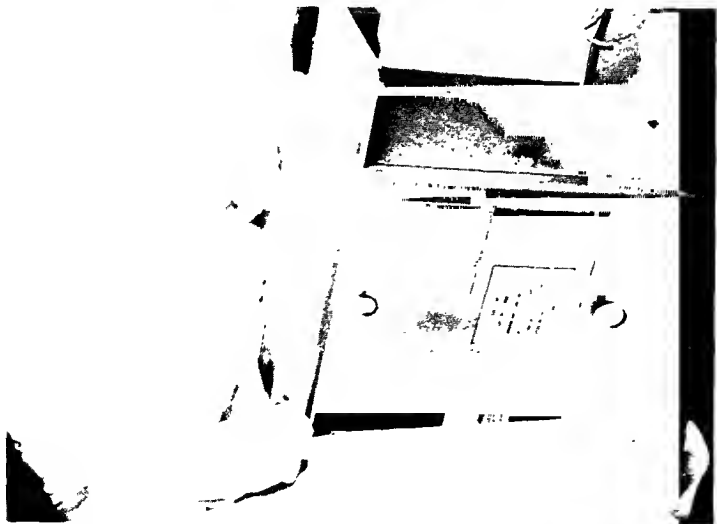
Photomicrographs of cross sections of cotton fibers selected to show a range of geometrical patterns at this size. 1, *Almonia Americana* (1); 2, coarse *Almonia* (upland); 3, very coarse *Almonia* (extra-long-staple) (See also tables 2 and 3)



1. Composite photomicrograph of longitudinal views of mature fibers showing different degrees of fineness over a wide range as found in American upland cotton. Magnification in all cases X 165.



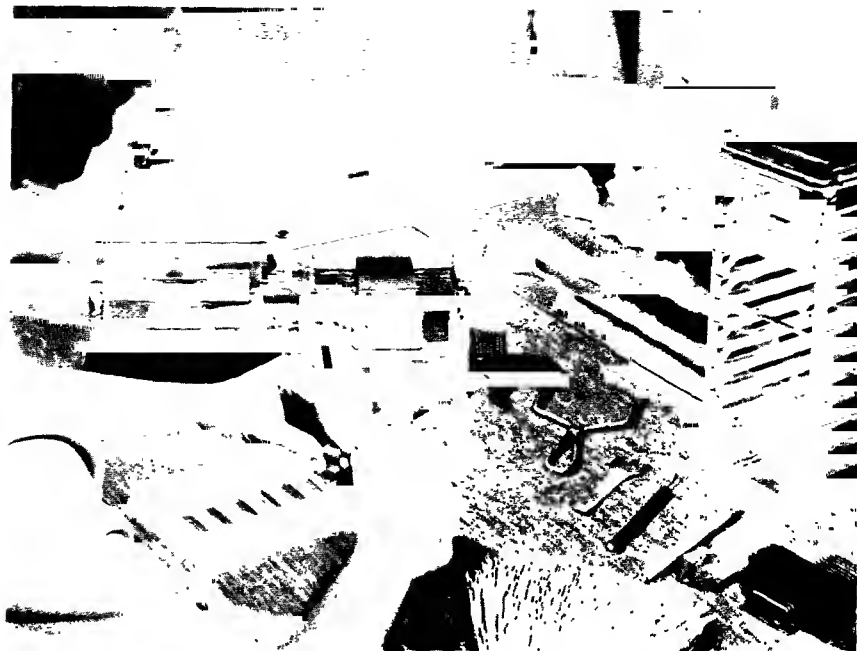
2. Composite photomicrograph of longitudinal views of fibers showing variations in degree of maturity or cell-wall thickening over a wide range as found in American upland cotton. Magnification in all cases X 165.



1. Technician making tests for determining the color of cotton lint as it naturally comes from the gin or bale, using the Nickerson-Hunter Cotton Colorimeter. This is a photoelectric instrument whose readings are calibrated in terms of the Universal Cotton Grade Standards, permitting the grade designation of a sample to be read directly and instantaneously from an illuminated graphic chart.



2. Technician blending a sample of ginned lint using the Gaus-Larison mechanical cotton fiber blender. Owing to the great variations existing in the distribution and proportions of cotton fiber types throughout a sample, the determination of most fiber properties requires a preblending of the cotton in order to give representative and reliable test specimens.



1. Technician performing fiber-length tests on prepared test specimens of cotton lint using the Suter-Webb Duplex Cotton Fiber Sorter. This instrument permits a stratification of the many fiber-length groups occurring in any sample of cotton and the formation of a cotton-fiber-length array from which the length distribution can be accurately evaluated for the entire sample, and various statistical values calculated for its central tendencies and variability.



2. Technicians making fiber-length tests on cotton lint using the Hertel Digital Fibrograph. This is a photometric instrument allowing a scanning of the combed and specially prepared sample whereby various length statistics of the fiber length distribution can be evaluated.



- 1 Technicians using the Smith-Sheffield Micronaire instrument to evaluate fiber fineness and maturity in combination as possessed by cotton lint. The Micronaire scale values observed represent averages for the respective test specimens.



- 2 Technician determining the average fiber strength of prepared test specimens of cotton lint using the Pressley flat-unwrapped-bundle tester. The gauge spacing generally used between the two zipping jaws of the fiber bundle is either 0 or 1/8-inch. The strength results may be expressed as the initial Pressley index observed, or some other calculated index, or 1,000 pounds per square inch, or the new textile measure of grams per tex.

of time, the Federal plant scientists found their needs so far beyond the capacity of Webb's laboratory to meet their requirements that the decision was taken to split his staff again, giving the Plant Industry group its own laboratory and personnel.

The repeated splitting off of parts of Webb's original organization did nothing, however, to retard the progress of the new science. Rather its effect was that of proliferation. At the University of Tennessee an energetic young physicist, Dr. K. L. Hertel, had now come into the field with a "fibrograph," a photoelectric instrument designed to speed the evaluation of certain fiber-length statistics, which was to be but the first of a number of valuable inventions of laboratory apparatus. At the Massachusetts Institute of Technology, the late Dr. George B. Haven and Dr. Edward R. Schwarz who, through early association with Dr. Webb in the American Society for Testing Materials, had been encouraged to push onward with optical studies of the structure of cotton fibers, were also making useful contributions. Meanwhile, there had also been formed two important new industry groups to promote scientific studies—the Textile Foundation and the Textile Research Institute—both of which had turned the power of their resources upon the study of fibers. Interest in fiber science had indeed become contagious; the intriguing potentialities and the promise of professional reward were attracting an increasing number of alert and earnest young scientists in a dozen or more research laboratories over the country.

Then, in the early and mid-1940's, almost without warning came a veritable explosion. First, a number of manufacturers, confronted with the necessity of meeting firm specifications in their contracts for military goods, and aware through their own industry organizations of the need of precise raw material analysis, began, one by one, to set up fiber laboratories of their own. As they did so, they also began to require of their cotton shippers that the raw cotton supplied them pass certain laboratory tests of fiber strength, fineness, and maturity. This was a serious development from the standpoint of the cotton merchants and shippers, who in turn, for their own protection, were compelled to find means of ascertaining in advance of shipment results from the laboratory analyses of the cottons they offered and sold to the mills. Government facilities were wholly inadequate to handle the volume of work that thus developed. To meet the increasing demand, a number of commercial testing firms stepped into the breach and established custom laboratories to provide the wanted service. Then, in the course of a little time, the stronger and more progressive of the cotton merchant firms equipped themselves with laboratories of their own, and some prepared to subject all or most of the cotton they handled to laboratory analysis.

The widespread adoption of the new laboratory techniques, both by manufacturers and by merchants, was greatly accelerated, as the numbers of laboratories and workers increased, by a second wave of inventions, which for the most part had the effect of shortening the time required to obtain the wanted results. Of these, one of the most important was the Micronaire, an invaluable contribution of William Sharrott Smith, one of the younger men who after a number of years with Webb had left his organization and joined the staff of a laboratory newly established by the West Point Manufacturing Company. Smith discovered that by measuring the flow of a current of air at known pressure through a small sample of cotton (50 grams) confined in a chamber of known volume, a reading could be obtained in a moment's time upon a scale which gave an index, within limits, of the average fiber fineness in combination with the average fiber maturity of the cotton—an observation which up to that time could be made accurately only by calculation from a laborious series of fiber sortings, weighings, and microscopic evaluations. Smith's Micronaire apparatus was developed through cooperation with the Sheffield Corporation.

Further refinement was later to be made in the widely used Micronaire fiber test, the index readings of which reflect without discrimination the content of highly desirable fibers of fine caliber, normally developed, and of flaccid, immature, and thin-walled fibers deleterious to yarn quality and spinning performance. Because low Micronaire values are known generally to be influenced by abnormally high percentages of immature fibers, the Micronaire index alone is invaluable to spinners in detecting bales in which the percentage of immature fibers is greater than their work can tolerate. It remained for Samuel T. Burley, Jr., a long-time and highly perceptive worker in the research program originated by Dr. Webb, to conceive a process in which, by mercerizing the Micronaire sample with a caustic soda solution after its first reading and subjecting it again to the Micronaire test, it becomes possible to read on a second scale an index figure which permits an evaluation of cotton fineness and maturity independently of each other, and substantially explains the degree to which fiber immaturity actually influenced the originally observed Micronaire value. That is known as the Causticaire Method. To establish the Causticaire Scale required meticulous calibration with data laboriously gathered from weight-per-inch and maturity analyses of a great number of cottons throughout the quality gamut. In this phase of his work, Burley often sought statistical evaluations and counsel of Webb, whose role as mentor to younger men was often to be repeated. Burley was subsequently to be given charge of the development and operation of Agriculture's new pilot plant at Clemson, S.C., for special cotton processing and fiber-testing studies.

In Arizona, E. H. Pressley, an agronomist on the staff of the Agricultural Experiment Station, and fellow alumnus of Clemson, who in association with the late T. H. Kearney had followed the progress of Webb's work, discovered that by certain improvements in the Chandler wrapped round-bundle strength method, the aggregated strength of cotton fibers, paralleled in a flat unwrapped bundle, could be obtained more easily and with a marked saving of time.

But, going back to an earlier time, between 1930 and 1940 with Webb's inspirational guidance Malcolm E. Campbell and a select staff, working under a cooperative arrangement in the spinning laboratory of Clemson College, were helping to speed the processes of fiber analysis and the interpretation of experimental results by originating and calibrating methods for successfully spinning small samples of cotton into yarns, and by developing a systematic and comprehensive series of visual standards for accurately evaluating yarn appearance. These two achievements did much to give practical application and effect to the new and rapidly developing fiber science. The teamwork of Webb and Campbell during the pioneer years was outstanding and proved highly advantageous to furthering the objectives of the broad program. During the latter part of the same period, Campbell with the aid of Clarence Asbill, a skilled engineer with great originality of mind, developed preliminary specifications, designs, and plans for building a small-scale textile slasher which, at that time, constituted the bottleneck to weaving any fabrics from small lots of yarn. This project was carried to conclusion in later years by other workers following the leads of Campbell and Asbill. Thus, it is now possible to weave small samples of fabric from small lots of yarn, in connection with various cotton research and testing programs, and this development has given further practical application and effect to cotton fiber technology. Asbill was subsequently to add impressively to his inventions of needed apparatus at the Department's Southern Regional Laboratory and at the North Carolina State College where he is now engaged in advanced instrument designing.

Meanwhile the Southern Regional Research Laboratory at New Orleans, now a part of USDA's Agricultural Research Service, was driving ahead on a program of a different kind. Research up to this time had been aimed at isolating the elements of quality in cotton fibers, evaluating them singly and in combination, and at establishing an understanding of the relationships between fiber properties and the properties of cotton products. The southern laboratory approached the subject from the standpoint of the products and, with the purpose of stimulating an increased utilization of surplus cotton supplies, sought to enhance the usefulness of cotton by modifying its properties the

better to condition it to fulfill its end-use functions. To a major extent this is a task for chemistry, and true to its chemical ancestry (in point of organization the utilization laboratories are lineal descendants of the one-time Bureau of Chemistry and Soils), the southern laboratory began by emphasizing experimentation with chemical treatments of raw cotton, as well as engineering-type studies designed to increase processing efficiency. By introducing cross linkages of various kinds and degrees and modifying the molecular structure of cellulose without destroying the general fiber configuration, remarkable successes have been achieved in such directions as resistance to heat, sunlight, bacterial, and fungous degradation, and to flame and glow resistance, among others. Parallel to or in cooperation with the work of private organizations, basic studies of resin finishes have contributed to the development of crease retention and wrinkle resistance in wash-and-wear apparel fabrics. Subsequent reorganizations have brought about the consolidation in the Southern Regional Laboratory of much of the Department's physical studies of cotton fibers.

In addition to the credit to which Dr. Webb is entitled for his own researches, credit must also be given to him for the insight and judgment with which he selected his coworkers. For the alumni of the little band that he first brought together head the honor roll of the profession and their achievements are, in themselves, an impressive tribute to his early leadership. Notable among those already mentioned are, of course, Dr. Campbell, now Dean of the School of Textiles at the North Carolina State College, the largest textile school in the United States, who is known and respected as an outstanding educator in this field not only in this country but throughout the world, and himself the director of a front-rank research program at his own institution.

Similarly there is Miss Dorothy Nickerson, whose dramatic progress in color analysis, the simulation of daylight and the control of illumination led to the development of a phenomenal electronic instrument, the Nickerson-Hunter Colorimeter, which automatically registers on a scale instantly and accurately all that the human eye can see of color and luster. Notable as have been her contributions in the field of cotton quality analysis, her guidance has been widely sought—as far afield in fact as in the motion-picture industry. Among the honors that have come to her are fellowships in the Optical Society of America, the Illuminating Engineering Society, and the American Association for the Advancement of Science. She is a delegate from both the Optical Society of America and the American Society for Testing Materials on the Inter-Society Color Council, one of three representatives of the Optical Society of America to the International Commission on Illumination, and serves as Chair-

man of the U.S. Committee of Color Rendition for the U.S. National Technical Committee of the International Commission, and as one of three Special Trustees of the Munsell Color Foundation.

One of Webb's earliest staff members and closest coworkers was T. L. W. Bailey, Jr., who perfected a highly skilled technique for studying the cross-sectional conformations of cotton fibers, and who accumulated the first large volume of data from the measurement of a wide range of commercial and experimental cottons. His contributions of methodology and data and his illuminating cross-sectional diagrams proved to be of extraordinary value to scientific workers in cotton agriculture and the textile industry. Subsequently, Bailey continued and expanded his scientific work on cotton fibers at the Department's Southern Regional Laboratory in New Orleans, and later at the Institute of Textile Technology in Charlottesville, Va. Now with the Foreign Agricultural Service of USDA, he is carrying on important technical liaison work between research agencies of the United States and spinners of American cotton abroad.

Dr. Carl M. Conrad, early recruited by Webb as a chemist, first did invaluable work with his group of assistants in calibrating, improving, and standardizing the methodology involved in four promising physical tests, namely, fiber length array, fiber strength (Chandler wrapped round bundle), fiber weight fineness (array method), and fiber maturity and immaturity. Much of the later success of Webb's research and testing program was due to the many solid contributions that Dr. Conrad and his assistants made toward perfecting and standardizing the techniques and apparatus used in those four tests. Later, Dr. Conrad and his staff made extensive analytical studies on the chemical composition of cotton fibers and on the soundness of their cellulose, the latter of which was done by fluidity, methylene blue, and alkali-solubility tests. Many of the samples represented different varieties, growth conditions, ages, and degrees of weathering and wear. Thus, a large body of interrelated data was developed from these studies which served many useful and practical purposes. Subsequently, Dr. Conrad continued and expanded his research along these lines in the Department's Southern Regional Laboratory at New Orleans. Now he is Head of the Cotton Fiber Pioneering Research Laboratory of that institution and the laboratory staff under his guidance is doing fundamental exploratory work of the first order of importance. Over the years Dr. Conrad has taken an active and responsible part in the work concerning national and international standardization with respect to cotton fiber testing, measurements, and evaluations, as sponsored by the American Society for Testing Materials, by the American Standards Association, and by the International Standardization Organization.

Following the early X-ray studies started on cotton fibers by Mrs. Farr and later by Dr. Wayne Sisson, a young botanist, Dr. Earl Berkley, was assigned to Webb's staff about the mid-1930's, through a cooperative arrangement with the former Bureau of Plant Industry, to intensify and expand the X-ray studies of crystalline cellulose in cotton fibers. Dr. Berkley and his assistant, Orville Woodyard, developed extensive interrelated information bearing on cellulose orientation, strength, and cell-wall development of cotton fibers, much of which represented successive stages of fiber growth from flowering to maturity. They also developed basic data on the cell-wall structure and shrinkage of cotton fibers in general. Dr. Berkley, later for a number of years Director of the American and foreign-based laboratories of Anderson Clayton & Co., is now Director of Fiber Research and Testing for the Deering Milliken Service Corporation.

Others of Webb's early staff who have won distinction are: Mason Dupré, subsequently Assistant to the Director of the Department's Southern Regional Laboratory at New Orleans and now Assistant to the Washington Director of the Department's Agricultural Research Administration for Cotton Utilization Research and Development; George Pfeiffenberger, for some years laboratory director for Chicopee Manufacturing Co., subsequently for Otto Goedke, one of the first cotton merchant firms to adapt the new laboratory techniques to the selecting of cottons to meet the particular requirements of its mill customers, and now Executive Vice President of the Texas Plains Cotton Growers, Inc., where he is promoting and encouraging extensive research and testing for improving and preserving cotton quality; Murphy Cook, now Director of the cotton fiber laboratories and related technical phases of the worldwide cotton merchant firm of George H. McFadden Bro.; John T. Wigington, Director of the Technical Division of the American Cotton Manufacturers Institute, through which technicians from mills of member companies are trained in the techniques of quality analysis; and W. J. Martin, USDA extension cotton utilization specialist, whose function is to carry to the spinners of the country the lessons of the laboratory findings and experience.

Still others are: the late Dr. Enoch Karrer who, until his death some years ago, was Head of the Physics Section of the Department's Southern Regional Laboratory; J. N. Grant, now Head of the Physics Section of that laboratory; E. W. S. Calkins, cotton fiber specialist with U.S. Rubber Co.; Arvid Johnson, research and development specialist for the Lumus Gin Co.; Roland L. Lee, Jr., Chief of the Textile Division of the U.S. Tariff Commission; Leo Gerdes, a consultant on cotton ginning and a columnist for the Cotton Trade Journal; Scott Shaw, active in the development of improved methods and apparatus for the Department's cotton ginning investigations;

George Gaus, working on instrumentation problems in the Department's cotton-quality research program, and who holds 24 U.S. patents covering past inventions of apparatus for cotton testing, bale sampling, and ginning; the late Dr. Norma Pearson who became an authority on neps and other imperfections of cotton quality; James H. Kettering who, until his recent retirement from the Department's Southern Regional Laboratory, made important advances in knowledge of the chemical phases of raw and chemically modified cotton fibers; William H. Gray, in charge of the fiber testing and processing laboratories of the Cotton Division, AMS, at Clemson, S.C.; and Joseph T. Rouse, Head of the Washington Testing Section of the same organization.

Some appreciation of the vitality of cotton fiber research may be had by noting the extent to which it has been expanded and to which its results have found application in industry. From a bare handful of cotton fiber research and testing laboratories in the world, of which Webb's laboratory in the Department of Agriculture was the first of importance in this country, the number has grown in 30 years to more than 325, of which over 180 are in the United States. Today hardly any mill or merchant house dares rate itself in front rank that does not possess at least some laboratory equipment and trained laboratory personnel. The cotton textile industry, impatient to push forward to a greater mastery of the technical problems inherent in its raw material, has established for itself such splendidly equipped and supported research and service institutions as the Institute of Textile Technology at Charlottesville, Va., and the Textile Research Institute at Princeton, N.J. Moreover, the commercial research laboratories of Milton Harris Associates at Washington, D.C., and the Fabrics Research Laboratories, Inc., formerly at Boston but now at Dedham, Mass., under the direction of Dr. Walter J. Hamburger, must be credited with important contributions of new apparatus, techniques, and knowledge, while the U.S. Testing Company with headquarters at Hoboken, N.J., has been concerned with the development of instruments and methods for the rapid evaluation of cotton quality.

The coordination of test results in these numerous laboratories has itself become a function of the U.S. Department of Agriculture, in cooperation with two other American and two European laboratories. To promote uniformity of methods for cotton fiber testing instruments used commercially throughout the world, an International Cotton Calibration Standards Committee was formed in 1956. This, it may be said, was the fruition of ideas earlier germinated but long in maturing. More than 20 years before, Dr. Nazir Ahmad, then Director of the Technical Laboratories of the Indian Central Cotton Committee at Bombay, and Webb had engaged in a series of letter exchanges, agreeing on the need of international standardization of laboratory

test methods, and exploring the possibilities of developing working procedures to that end. Frustrating circumstances led both to conclude that the times did not favor this bold approach and that, although international action would inevitably come in the future, it would have to await more general understanding of the purpose and more substantial support for the project. The test methods now used are those recommended by the American Society for Testing Materials, some of them having been first adopted in their original form during Webb's tenure as Chairman of its Raw Cotton Section. Calibration is accomplished by distribution of "calibration cottons" tested and approved for uniformity in the laboratory Webb established for standards research. Use of the standard test cottons, under this International Cotton Calibration Program, represents a milestone of progress, for the fiber test results obtained in all laboratories using the check-test cottons become more comparable, meaningful, and interchangeable than otherwise would or could be possible.

One further important outgrowth of the cotton fiber research program is the publication of current technical information on the crop, a service inaugurated by the Department of Agriculture in 1947 under the direction of Dr. John W. Wright. From its more modest beginnings in that year, the Department of Agriculture has advanced to the publication at biweekly intervals of detailed laboratory reports of the length, fineness, strength, maturity, color, spinning behavior, and product quality of the principal standard varieties grown in the major defined marketing areas of the cotton States. It follows at the end of each crop season with a summary report containing all the fiber, processing, yarn, and fabric data accumulated throughout the year. The current semimonthly information has proved invaluable in the marketing of the crop, the annual summaries being even more so to producers and their counsellors concerned with the achievement of higher quality production in their particular local areas. This service stands solidly on the foundation of fiber research initiated by Webb and his associates, without which it would hardly yet be possible.

Although in most ordinary market transactions cotton classing continues to be the first means of cotton quality evaluation and selection, wherever precision is essential, reliance is placed on laboratory analysis. In trade and manufacturing, the Micronaire test as a supplement to classing is general. Many mills now regularly specify in their raw cotton purchase contracts a minimum or range of Micronaire values. In the 1957-58 season, for example, an extensive study recently made jointly by the Agricultural Experiment Stations of 13 cotton-growing States and the Agricultural Marketing Service of the Federal Department of Agriculture showed that approximately 86 percent of American cotton purchased by cotton mill firms in this country represented shipper contracts with fiber test specifications for

fineness, or "Micronaire clauses," included. Many users of American cotton abroad likewise require their imports to meet definite Micronaire specifications. Approximately 10 percent of the shippers' contracts with manufacturers in this country also specify Pressley strength values. Interest in this respect, however, may be even greater with manufacturers in foreign countries than with those in the United States. In a few instances, cotton merchants are now willing to guarantee to a mill customer that the cotton they supply will produce a textile product that will meet the specifications imposed by the mill's customer.

As to cotton purchased directly by manufacturers in this country, the recent survey for the 1957-58 season showed that slightly more than 75 percent of it was reported to have been tested for fiber fineness prior to purchase. The proportion of cotton actually purchased by test, however, is likely to be larger than the figure cited, as practically all cotton obtained directly from areas nearby cotton mills is subjected to prior Micronaire tests, and little, if any, is purchased that does not meet the minimum or range of Micronaire values required.

The survey results reported above are now 3 years old. Use of instruments to measure cotton quality has increased appreciably since then among cotton mills and shippers, but the extent to which instruments were used even 3 years ago is impressive. It shows a trend which is likely to move much faster in the future, cotton mill men say.

In the approach toward the objectives at which cotton fiber analysis was originally aimed—the improvement of grade and staple length standards—progress has been gratifying. While technical measurements obtained from the cotton fiber and color laboratories have not yet been actually incorporated in legal definitions of the standards, they are nevertheless heavily depended upon in the day-to-day operations and decisions involved. The Universal Standards for grades are prepared by the U.S. Department of Agriculture with the help of laboratory measurements of color and the use of laboratory reference data. The official standards for staple length, likewise in use around the world, are prepared with the help of precise laboratory measurements of fiber lengths, uniformity, fineness, maturity, and strength. The grade and staple standards are, consequently, now more accurate, constant, and reliable than ever before. Results obtained from cotton-fiber analysis also give a stable basis for checking the level and accuracy of daily cotton-classing operations, and thus contribute substantially to the uniformity of Federal and commercial classing services.

If, however, one were called upon to single out that segment of the industry where the benefits have been most telling, quite certainly he would have to say that it is raw cotton production, and specifically the

improvement of American varieties. With the knowledge that fiber analysis has given them of the strength, fineness, length, uniformity, and other features of their cottons, and with such light as research has so far been able to shed on the combinations of these properties that give a cotton superior spinning value, cotton breeders in the United States have done a magnificent job, and on a nationwide scale. Most of this improvement has come about in the last 20 years; within that time, it is said, as much advance has been made in cotton as in automobiles. Fiber fineness of the crop overall has probably increased by more than 10 percent. In 1940 a pound of typical 1-inch cotton contained about 90 million individual fibers; today the number approximates 100 million. Great progress has also been made in the breeding of cottons of greater uniformity of length. Seed stocks of the cottons of known superiority have been multiplied over and over; many of the varieties shown to be inferior have disappeared from the scene.

Much of this improvement has been carried over into the baled crop; and, were it not for a new factor in the equation—that of mechanical harvesting—most, if not all, of this remarkable achievement should be evident in the cotton delivered at the mill door. But mechanical harvesting, essential as it is in the competitive push to hold down production costs, has brought a series of new problems for the ginner. Pressure for a solution of these problems of cleaning, drying, and ginning mechanically picked cotton has been greater than the original Federal ginning laboratory at Stoneville, Miss., could sustain. To meet the demand, two additional laboratories have been added, one for the Southwest region at Messilla Park, N. Mex., and the other for help with problems of the Southeastern region at Clemson, S.C. The knowledge of sound ginning practices developed in these three institutions, each now with its own fiber laboratory, is carried by State and Federal extension specialists and communicated in a practical manner to ginneries in 16 cotton-growing States. In turn, it is translated by them into the conservation of producers' values through better ginning.

Cotton now has to be better than ever. No longer is it enough to meet the more exacting specifications of textile end-products; in the modern mills of today, where processing costs are cut to the bone, machines are operated at speeds never thought to be attainable in times past; and, in some instances, intermediate processes, once believed necessary in spinning, have been eliminated altogether. Each advance in manufacturing techniques makes a new demand on the quality of the raw material. Thus the goal of research lies always farther ahead.

In a sense, nevertheless, it may be said that fiber science has now come of age. The literature grows apace. In its Fiber Society and other professional organizations, scores of intent workers meet regu-

larly for discussion and mutual stimulation. In the nation's textile schools, fiber science and technology are firmly imbedded in the teaching curricula and research. The National Cotton Council of America, federating the diversified interests of the entire cotton industry in the United States, has for some years lent the weight of its organization and the services of its own highly qualified staff to the further development of the field and the promotion of wider applications of the new techniques.

To fathom the significance of the masses of mathematical data on cotton fiber properties of widely diverse characteristics accumulated over the years, and the corresponding masses of figures on the properties of yarns and fabrics produced from them, it has remained to trace out, by higher statistical analysis, the abstruse causal relationships between cotton-fiber properties and product qualities. None was better equipped for this task, and none more earnest in wanting it done than Dr. Webb. Accordingly, in 1941, he initiated a program of this kind with the statistical assistance of his two long-time professional associates, Howard B. Richardson and Gordon L. Austin. A series of 22 professional papers are the result of their combined efforts up to this time, with more to follow. Together they constitute for students the world over what is generally considered to be the authoritative reference work on the elements of raw cotton quality in relation to processing performance and yarn quality. These reports, moreover, have been translated into various foreign languages, distributed to members of trade and textile associations abroad and at home, and they are used in teaching at textile schools abroad as well as in this country.

During the active years remaining to him, Dr. Webb will be engaged in the study of a complex series of problems of much importance. In particular, he will be completing a large number and wide range of correlation analyses having to do with the interrelationships naturally occurring among cotton fiber measures and with their disturbing effects on evaluations of the contributions of the respective fiber properties to yarn strength and yarn appearance. These mathematical investigations are of a highly exploratory nature; Dr. Webb thus continues to be a pioneer in the final plateau of his work no less than in his earlier years.²

Meanwhile, in some dozens of laboratories, the researches go on pushing out ever farther the borders of the unknown. New problems are being recognized, new advances in skills and techniques are being made, new and improved apparatus is being developed, new leaders are coming forward, new workers are joining the ranks, relationships and interrelationships are being newly discovered, and new applications

² Hon. John Sherman Cooper, Senator from Kentucky, had inserted in the Congressional Record for Sept. 2, 1960, an article entitled, "He Pioneered a New Science That Changed the Ways of a Great Industry."

are following. For cotton, as in all research, the goals lie always farther ahead, with still greater benefits yet to be gained.

ACKNOWLEDGMENTS

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The cotton fiber cross sections pictured in plates 3 and 4, resulting from the application of exceptional skill and technique on the part of their maker, were prepared by T. L. W. Bailey, Jr., one of the first recruits in Dr. Webb's original cotton fiber research program.

TABLE 1.—*Cotton fiber cross-sectional data for 3 figures in plate 3*

1. Fine fiber, Sea Island cotton:	
Average total area.....	80.62 square microns
Average wall thickness.....	2.26 microns
Average ratio axes: major/minor.....	2.80
Average fiber diameter.....	14.28×5.79 microns
Approximate wt./in.....	1.82 micrograms
2. Fine fiber, American upland cotton:	
Average total area.....	127.50 square microns
Average wall thickness.....	2.86 microns
Average ratio axes: major/minor.....	2.80
Average fiber diameter.....	18.19×7.15 microns
Approximate wt./in.....	3.44 micrograms
3. Medium fiber, American upland cottons:	
Average total area.....	148.83 square microns
Average wall thickness.....	2.68 microns
Average ratio axes: major/minor.....	3.37
Average fiber diameter.....	22.03×6.75 microns
Approximate wt./in.....	4.20 micrograms

TABLE 2.—*Cotton fiber cross-sectional data for 3 figures in plate 4*

1. Medium fiber, American upland cotton:	
Average total area.....	178.67 square microns
Average wall thickness.....	3.36 microns
Average ratio axes: major/minor.....	3.29
Average fiber diameter.....	22.91×7.89 microns
Approximate wt./in.....	5.30 micrograms
2. Coarse fiber, American upland cotton:	
Average total area.....	252.86 square microns
Average wall thickness.....	4.30 microns
Average ratio axes: major/minor.....	2.82
Average fiber diameter.....	25.60×9.85 microns
Approximate wt./in.....	7.92 micrograms
3. Very coarse, Asian cotton:	
Average total area.....	606.02 square microns
Average wall thickness.....	9.33 microns
Average ratio axes: major/minor.....	1.52
Average fiber diameter.....	29.42×20.50 microns
Approximate wt./in.....	20.30 micrograms

TABLE 3.—*Cotton fiber cross-sectional data for 3 figures in plate 3 and 3 figures in plate 4*

Selected cottons	Average total area, in square microns	Average wall thickness, in microns	Average ratio axes: major/minor	Average fiber diameter, in microns	Approximate wt./in., in micrograms
1. Fine fiber, Sea Island..	80.62	2.26	2.80	14.28× 5.79	1.82
2. Fine fiber, American upland.....	127.50	2.86	2.80	18.19× 7.15	3.44
3. Medium fiber, American upland.....	148.83	2.68	3.37	22.03× 6.75	4.20
1. Medium fiber, American upland.....	178.67	3.36	3.29	22.91× 7.89	5.30
2. Coarse fiber, American upland.....	252.86	4.30	2.82	25.60× 9.85	7.92
3. Very coarse fiber, Asian.....	606.02	9.33	1.52	29.42× 20.50	20.30

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This partial list of references, selected from several thousand and including some not heretofore publicly cited, is intended to afford historical perspective on the origins and development of cotton-fiber science in the United States. Accordingly, the list has been limited to writings by American authors and does not include citations of contributions to the world literature by scientists abroad, many of which, especially those published in England, Continental Europe, Egypt, India, Pakistan, and Japan, have proved most valuable and stimulating to progress in this country. The list includes only references to testing methods and apparatus in relatively wide use and those thought to be historically important in their development. Publications relating to instruments and techniques designed for limited research purposes and some of those identified with apparatus and methods adapted particularly to the study of single fibers, in contrast to groups of fibers, have not been included. A complete bibliography, moreover, would include titles of a great number of contributions in the United States in such specialized areas as the chemical modification of cotton fibers; fiber modification in the ginning process, including drying, cleaning, and compressing, and in the various mechanical and finishing processes of textile manufacture; as well as the geometric and factorial design of yarns and fabrics for specific apparel, household, and industrial uses. Space limitations dictate many painful omissions of the kind, the importance of which is recognized and no less appreciated.

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Rice—Basic Food for One-third of the Earth's People

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[With 6 plates]

RICE, cultivated since the dawn of history and symbol of prosperity in many countries of the Far East, is the staff of life for over a billion human beings. It has fed the teeming populations of India, Indochina, and south China since time immemorial, and was introduced into the Near East by the Persians. From Babylonia and lower Syria the Arabs spread its cultivation around the Mediterranean Sea, probably first into Egypt, then in the 11th century into Spain, Italy, and the Balkans.

RICE IN THE NEW WORLD

Rice was introduced into the New World by the Spaniards, probably by Columbus on his second voyage in 1493. He arrived in Hispaniola with citrus fruits, vegetables, and grains. In the early 16th century rice cultivation spread all over those tropical lowlands where the culture of sugarcane was introduced. In the early slave days it was important as an easily preserved food for the slaves.

However, the question of alternative starches soon arose. Both sweet and bitter varieties of yuca—native to the New World—were soon preferred to rice, perhaps because they were cheaper and easier to grow. Further, yuca was a rootcrop, hence hurricane proof. Indeed the sugar planters of Jamaica were required to furnish each slave a plot of ground on which he could raise sufficient provisions for his maintenance, and they were further required to plant upon "their plantation in ground-provisions, at least one acre of land for every ten negroes."¹ Yuca could be dug up as needed and did not have to be stored. When necessary, bitter yuca could be made into a meal (farinha or cassava) and kept for a long time. Although yuca

¹ Edward, Bryan, *History of the West Indies*, vol. II, p. 152, London, 1793.

was lacking in flavor, it was filling; a slave must eat what is provided; he cannot choose. Also, there were corn and plantains as competitive starches, often available in the absence of yuca. Although rice never became the almost universal staff of life in the New World that it had been for millennia in the Far East, paddy rice and, in a limited measure, dry rice, were grown to some extent all through the Colonial Period.

During the 19th century New World sugar plantations increased in size as herculean efforts were made to cater to the world's sweet tooth. As the plantations became more and more market-oriented, factory methods were introduced wherever feasible. It was less expensive and much less trouble to import cheap food for cane cutters and for sugar-mill workers than to grow it locally. Rice, which shipped well and kept well under tropical conditions, could be imported at ridiculously low prices from the Far East.

Between World Wars I and II great changes in the rice picture took place all over the world. Nationalism was rampant everywhere. The republics in the New World began to insist that agriculture be diversified in order to cut down on unemployment and underemployment and to resist economic colonialism. Great emphasis was placed on rice culture, since that grain had become more and more important in the diet. "Grow it at home" became the watchword. Even countries that tried to assure themselves of an exclusive market for their sugar demanded the right to buy rice in the cheapest market and not necessarily from the countries that imported sugar.

BRAZIL

Rice consumption in Brazil is very important, and production has greatly increased in recent years as seen in the following table:

Mean annual rice acreage and production

	<i>Hectares*</i>	<i>Metric tons</i>
1932-38-----	956,000	1,385,000
1948-52-----	1,927,000	3,025,000
1953-57-----	2,492,000	3,691,000

* 1 hectare = 2.471 acres.

Dry rice, cultivated in savanna or brush country, accounts for a large part of Brazilian production. Only in southern Brazil has paddy rice been important. It is possible that recent Japanese settlers along the Amazon will change this picture. Dry rice, dependent on rainfall, is subject to great fluctuations in yield from year to year. The fluctuations in production account for the great variations in rice exports, which averaged 54,000 tons before World War II, 147,000 tons from 1948 to 1953, none for the years 1954 and 1955, 102,000 tons in 1956, and none again in 1957.

UNITED STATES

Rice was produced with slave labor during the early part of the 19th century in tidewater sectors of the States of Georgia and the Carolinas. But the limited market in the Caribbean was soon cut off, there was much more money to be made in cotton and tobacco, and the rice industry gradually died out.

The remarkable comeback experienced by rice culture during the past 30 years in the States of Alabama, Louisiana, Texas, and California was made possible by the introduction of mechanized techniques. Planting and harvesting operations are mechanized, chemical fertilizers are lavishly used, and the most up-to-date weedkillers and insecticides are spread over the fields by plane.

The effect of government price supports on increasing production in the postwar period can be seen in the following table:

Average annual rice production

	<i>Hectares*</i>	<i>Tons</i>
1934-38.....	338, 000	956, 000
1948-52.....	752, 000	1, 924, 000
1954.....	1, 032, 000	2, 912, 000

* 1 hectare=2.471 acres.

The small size of the domestic market, coupled with the great difficulty of finding foreign markets without recourse to further government subsidies in the form of export bonuses, forced the Government in 1957 to limit acreage in rice to only 542,000 hectares, on which, thanks to the continuous improvement in techniques, 1,956,000 tons of rice were produced. The United States has become one of the world's great rice exporters, averaging 72,000 tons during the years 1934-38, 583,000 tons from 1948-52, and 694,000 tons from 1953 to 1957. In recent years, exports have gone to Japan, Indonesia, and Pakistan, as well as to old customers in the West Indies such as Cuba and Puerto Rico.

RICE IN ASIA

JAPAN

Nationalism took a different turn in the densely populated areas of the Far East. Industrialization in Japan meant a terrific pressure on the capacity of that country to produce food, particularly rice. And the design of conquest of Asia by war, with the co-property sphere and all that, was as much to get new lands to supply foodstuffs as it was to get new raw materials for Japan's industries and new markets for its manufactured goods. Japan has been and still remains a rice-importing country. On the average, between 1934 and 1938 Japan produced 11,500,000 tons of paddy rice and imported 1,732,000 tons, whereas from 1953 to 1957 the average production was 13,000,000 tons

and the average import 1,000,000 tons. During the same years, however, imports of wheat increased from 97,000 to 2,000,000 tons, barley from 20,000 to 738,000 tons, and corn from 196,000 to 267,000 tons. And at the same time the population increased from 70 to 90 millions.

CHINA

The basic features of rural life in pre-revolutionary China could be summarized in two words: poverty and hopelessness. In a typical village a few landlords owned almost all the arable land, and the great majority of the farmers rented tiny plots. Rents were exorbitant, up to 40 percent of the value of a year's harvest, and they were due regardless of losses by natural calamity. The poverty of the farmer precluded good seeds, efficient tools, adequate fertilizing, and effective cultivation. Productivity was low and falling, starvation was more than likely in years of drought or flood, and indebtedness was an intolerable burden carried by the great mass of the people from generation to generation.¹

These immemorial peasants, farmers for at least 40 centuries, wanted above all to break the power of the rackrent landlords, and they seem to be willing to accept collective farming in order to do so. Red China's present leaders are aware that the procuring of a constant supply of wholesome food is the basic condition requisite for the building of a powerful nation; only a rejuvenated agricultural system, they feel, can supply the vast quantities of raw materials, the large accumulations of capital, and the protective foods for the workers that are necessary to build the new society.

There has been a spectacular increase in food grain production.

Rice production rose from an estimated 48.6 million metric tons in 1949 to 86.7 million in 1957 and probably 100 million in 1958. Wheat increased from 13.8 million tons to 24 million in 1957, and probably 30 million in 1958. Productivity in yield per unit of land has been equally spectacular. Yields in pounds per acre in 1949 and estimates for 1958 are: rice, 1,688 and 3,000; wheat, 573 and 1,000.²

At present, food production is increasing at the annual rate of 2.2 percent. China has been able to change from an importing (687,000 tons of rice on the average from 1934-38) to an exporting nation (263,000 tons from 1953-57). China exported 268,000 tons to the Soviet Union in 1957, and is now attempting to enter her rice in the markets of Japan, Pakistan, India, and Ceylon—even into Burma! Thus it may be said that—

the political revolution paved the way for the transformation of the rural economy, and the sociocultural reforms reinforce the economic development. * * * the non-economic factors play just as important a part in the mobilization of agricultural resources as the economic-technical ones.³

INDIA

In India, second producer of rice in the world after China, rice production has increased by more than 25 percent since pre-World

¹ China's agriculture, Focus, Amer. Geogr. Soc., New York, vol. 10, No. 8, April 1960.

² Idem.

³ Idem.

War II days (304.3 million hectares in 1937 against 388 millions in 1956), but the population has increased by more than 27 percent. In spite of this tremendous increase, India still imports between 3 and 4 million tons of food grain—largely rice—a year. With population increasing by 2 percent a year, there are an additional 8,000,000 mouths to feed. A Ford Foundation study concludes that at the present rate of population increase, India will be short 28 million tons of food grain a year for her population by 1966. Considerable imports of rice continue to be made, but they have decreased somewhat as a result of massive importation of substitute cereals, particularly of wheat, especially from the United States. One wonders if this grain deficit will continue to be made up—on a gift, barter, or low-price basis—by New World grains.

INDONESIA

Densely populated countries such as Indonesia, where rice alone supplies more than 40 percent of the calories in the diet, are aware that too great a dependence on rice imports might lead to instability in the economy. The country has been able to maintain a favorable balance of trade only by a severe cutback in imports plus trading arrangements and barter agreements with the United States and various other countries. Even so it has been importing about 700,000 tons of rice a year—roughly 8 percent of its consumption. At present rates of population growth it will need to import 100,000 tons *more* each year unless it can achieve an almost immediate production increase. To meet this challenge, Indonesia is launching a 3-year program aimed at making itself self-sufficient in rice by the end of 1962. The emphasis is to be in the intensified use of present lands rather than in long-term mechanized development of new lands. Insufficient capital, lack of trained technicians, and inadequate use of improved production practices have been brakes on the program to increase production.

BURMA

Burma ranks sixth among rice-producing nations of the world, but is No. 1 exporter of that grain (almost a third of the exports of the world). The effects of World War II are still felt, for Burma produced almost 7,000,000 tons of irrigated rice before the war, but averaged slightly less than 6,000,000 tons from 1953 to 1957. The population of the country increased from 15.6 million in 1937 to 19.9 million in 1956, or an increase of 27 percent. Since production has not reached prewar level, exports have greatly decreased—from 3,000,000 tons before the war to an average of 1,537,000 tons from 1953 to 1957. Most of this rice passes through Rangoon, greatest rice exporting center in the world, to India and Ceylon, Japan, and Indonesia. It remains

to be seen how attempts at self-sufficiency in Indonesia and elsewhere will affect the market for rice from Burma.

THAILAND

Of the cultivated land of Thailand 92 percent is devoted to rice production (see pls. 1-3). Irrigation works under construction will make possible an increase in annual production of 800,000 tons. In spite of an increase in population of 43 percent in 20 years (from 14.5 to 20.7 million), the high level of rice exports has been maintained, averaging 1,388,000 tons from 1934 to 1938 and 1,283,000 tons from 1953 to 1957. Rice production has more than doubled over the past 40 years. Most of this rice is moved by river junk to the great port of Bangkok, whence it is shipped to Singapore, Malaya, and Japan, and in lesser amounts to Indonesia and Hong Kong.

PHILIPPINES

The Philippines have for a long time been a rice-importing area, in spite of considerable production. The postwar period has seen a tremendous increase in production as a result of vast irrigation works and the mechanization of many phases of rice culture. The average annual production from 1932-38 was 2,179,000 tons, against an average of 3,271,000 tons from 1953-57. In spite of an increase in population of 45 percent (from 15.4 millions to 22.3 millions), imports have been kept at a minimum—only 53,000 tons from 1953-57, against 38,000 tons from 1932-38.

PROBLEMS IN THE FAR EAST

The food problem of Asia in general is of course made more and more serious by the tremendous growth of population. There has been at least a 30-percent increase in the last 20 years. This population has been kept alive in several instances by large-scale imports—particularly by imports of vast stores of surplus wheat made available at little or even no cost by the United States. The basic problem of the Far East continues to be that of feeding an exploding population. Japan once sought the solution to this problem in a mad policy of political and military expansion, and, as long as the problem remains, it could in the future act as a motive for similar adventures in commercial, political, or military expansion, on the part of almost any Asiatic country.

The officers of the Rockefeller and Ford Foundations, in discussing the problems of rice production with agricultural leaders throughout the world, and especially in Asia, found that rice improvement is a question of real concern wherever rice is grown, and that there was mutual agreement about the desirability of an international effort directed toward increasing the supplies of this vital food.

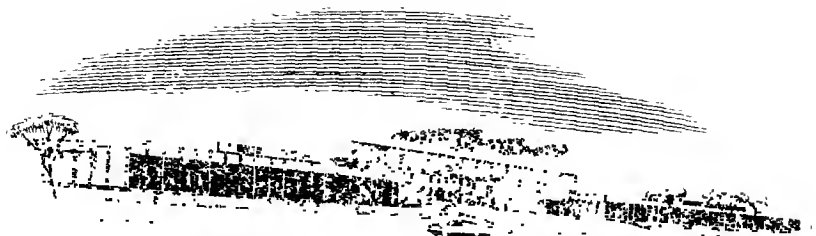


FIGURE 1.—Architect's sketch of proposed International Rice Research Institute to be built in the Philippines by the Rockefeller and Ford Foundations. Left, administration building; center, dormitory and community hall; right, laboratory building.

The two foundations decided to establish an international research institution as the best method for meeting the urgent need for rice improvement, and the Philippine Islands were selected as representing an excellent combination of advantageous factors. This International Rice Research Institute will be dedicated to the study of the rice plant and of its improvement, protection, production, and utilization. The institute will serve as a research center with a staff of senior scientists, as a training center at which younger scientists will receive instruction and gain experience in research methods under the direction of the staff members, and as a documentation center for the collection and dissemination of research results to interested workers in all the rice-producing countries of the world. The Government of the Philippines has wholeheartedly supported this project and has generously furnished land for the institute buildings (fig. 1).

In joining in this venture in better food production, the Ford and Rockefeller Foundations and their colleagues in Asia hope they are embarking on a program which over the years may become of increasingly vital significance to the citizens of those countries whose basic food crop is rice. As improved materials and methods, and increasing numbers of trained scientists specializing on rice begin to flow from the institute, higher quality rice will become increasingly available at costs within the reach of average consumers.⁵

RICE IN THE MEDITERRANEAN BASIN

EGYPT

Egypt is the most important rice-producing country in the Mediterranean Basin, with an area (1957) of 307,000 hectares and production of 1,709,000 tons. Grain for seed is carefully selected and the plots are heavily fertilized. Production is largely in lower Egypt, where year-round irrigation can be practiced, and where the soils can be progressively "flushed" of their salts. Formerly the grain was sown broadcast, but more and more rice seedlings are hand planted. Weeding, particularly of panicum, is done by hand. Exports were well over 100,000 tons in the early post-World War II period, then they

⁵ The President's Review, from the Rockefeller Foundation Ann. Rep. for 1959, p. 25.

ceased entirely as the result of political upheavals, to begin again in 1954. In 1957, 296,000 tons were exported, and Egypt thereby earned some much needed foreign exchange. But it is counter productive, to say the least, to export one grain food crop—rice, and import another—wheat.

FRENCH ISLE DE LA CAMARGUE—A DETAILED CASE HISTORY*

In France rice fields were reported in the vicinity of Perpignan at the end of the 13th century, and small plantings were reported in Provence from the 14th to the 16th centuries.⁷ The small amount of rice produced was probably used entirely or in large part as animal feed. At the beginning of the 20th century there were 800 hectares of rice in the Camargue. Fields to be used later for other crops were first planted in rice. The large quantity of fresh water used in irrigating this crop reduced the salinity of the soil to the point where it could be planted in other crops, particularly in alfalfa, wheat, or vineyards. However, yields were low, the grain produced was of poor quality, and milling was expensive in view of the competition of cheap rice imported from the Far East. By the end of World War I the growing of rice in the Camargue had been practically discontinued.

Up to World War II France had imported some 650,000 tons of rice a year from the Far East, 85 percent of which, cracked grains, were separated out in the process of milling and sold as animal feed. The rest, some 100,000 tons, was sold as rice for human consumption. In 1940 France was cut off from her traditional suppliers of rice, Indochina and Madagascar, and rice was rationed. Furthermore, in the postwar years the recently introduced hybrids of American maize produced such high yields at so low a cost that stock feeders turned to this new supply of feed, and the market for cracked rice disappeared. At the same time the consumption of rice in much of Asia increased rapidly. Under the lash of necessity, during the German occupation, some farmers in the vicinity of Arles began to think of again producing rice domestically, and in 1942, 250 hectares were planted in that crop which yielded 10 hundredweight to the hectare. They were at the northern apex of the Isle de la Camargue, the delta of the Rhone, in a sector seemingly made to order for pioneering in both crops and techniques.

The Isle de la Camargue, lying between the two principal mouths and distributaries of the Rhone, consists in part of semiarid grazing lands with their tough, halophytic vegetation, and in part of sectors covered with ponds and swamps and lagoons of fresh, brackish, or salt

* Field investigations in the Isle de la Camargue were conducted while the author was Visiting Research Professor at the University of Toulouse, under a Fulbright Award.

⁷ Le Riz, Centre National d'Information du Riz, p. 1, Paris, 1959.

water, where fish and wildfowl abound. This wild natural landscape, formed for the most part since the Romans established Arles at the then mouth of the Rhone, forms an enclave in the dry and smiling cultural landscape of Provence, with which it is in marked contrast.

The Isle de la Camargue was for millennia a land of scrub, semi-feral cattle (pl. 4, fig. 1), and of sheep that under the supervision of patient shepherds with their black dogs grazed on the tufts of coarse halophytic plants. It was "natural" grazing country, and the wealthy Ricard family entered the Camargue with big money to foster the raising of scrub bulls, wiry and fierce, for the bull fights at Arles, a popular tourist attraction. Tourists require roads, and now the Camargue is crisscrossed by an adequate network of highways.

Once the Camargue was thus made accessible, people with money as well as those with land were not slow in realizing that the "natural" conditions were most favorable for the introduction and expansion of rice production. On much of the land, level plots could be constructed with relative ease, and fresh water from the Rhone was abundantly available for irrigation. Those with small plots ideally located found it easy and relatively inexpensive to level them off and pump in the necessary water. Heavy investments have been made in the area, but rice growing is by no means left to the millionaire. The small farmer is very much in business, as witness the organization of buying, warehousing, and marketing cooperatives. Of the 2,000 rice growers, 1,500 cultivate less than 25 hectares, 300 between 25 and 50 hectares, 100 between 50 and 100, 85 between 100 and 150, and only 15 work more than 150 hectares.

It is estimated that at least \$10,000,000 has been invested in the growing of rice in the area since 1942, by private individuals and by cooperatives. Pioneering in techniques has paid off handsomely, for in 1959 there were 30,000 hectares in rice in the Camargue alone, and the average yield had increased fourfold in 17 years!

France now produces some 85,000 tons of polished rice, but the national market absorbs only 76,000 tons a year. Further, a commercial treaty with Madagascar requires France to import annually a certain tonnage of rice from that island. Hence France is both an importer and an exporter of rice. The problem of finding a foreign market is already acute.

In La Camargue those with ample capital often find it profitable to undertake costly operations to prepare a piece of land for the production of rice. As has been mentioned, much of the soil has a high salt content, which can most readily be decreased by the process of flushing, i.e., it must be drained as well as irrigated. Giant pumps hoist water from the Rhone for the irrigation of the rice fields. This water brings rich silt and plant food in colloidal suspension and also

dissolves and carries away excess salt. Drainage ditches must of course be dug lower than the rice field (pl. 4, fig. 2) from which the salt or brackish water is pumped.

French rice growers in the early years sowed their crop broadcast, largely to avoid the necessity of setting out by hand the tender shoots that have started in a bed; but they have more and more been forced to revert to hand planting because of the proliferation of certain aquatic weeds that have the same growing season as rice when rice starts from seed. These weeds in their early stages can be kept in check or given a handicap by working a field to be planted in rice with a tractor equipped with cage wheels (pl. 5, fig. 1). More and more dependence is placed on the setting out by hand of young rice plants, a task for which a machine has yet to be invented, and for which it has been next to impossible to hire or to train French laborers.

Seedbeds for rice seedlings are usually provided with natural fences of evergreen trees as a protection against the mistral that often blows vigorously down the Rhone Valley for days at a time (pl. 5, fig. 2). The back-breaking task of pulling up rice seedlings from the seedbed (pl. 6, fig. 1) and of transplanting them is done by hand by experienced laborers imported for the most part from Valencia, Spain, where rice growing, introduced by the Moors, has been an important activity for years. These workers are introduced into France under contract for a period of from 2 to 3 months for the tasks of planting, weeding, and spreading fertilizer.

Except for these stoop-labor tasks for which foreign laborers are imported, almost every other phase of rice production is mechanized. The bundles of young shoots were pulled by a tractor to the fields to be planted. Until recently the crop was harvested by hand (pl. 6, fig. 2); now it is for the most part harvested by specially adapted combine-harvesters, and is, of course, transported to the warehouse or market by truck.

In 1956 came the depression in the wine business. To cope with the wine surplus, the French Government encouraged shifting from the growing of grapes to the production of some other crop, particularly so if the vineyards were heavy producers. The vineyards in the Camargue are noted for their high yields and were on low ground that had been irrigated for a long time; hence they were ideal for the growing of rice, the new money crop. The result was that during the years 1956 and 1957, 6,000 hectares of vineyards were converted into rice fields. Thus the political factor has played an important role in the expansion of rice culture in the Camargue.

A revolution in rice growing has taken place in many parts of the world. For centuries it was considered axiomatic that rice could be produced only where labor was extremely cheap, as in India, China,



1. Puddling soil with a hand harrow. Note two large termite hills. The leaves of the trees left standing probably help fertilize the soil. Thailand.

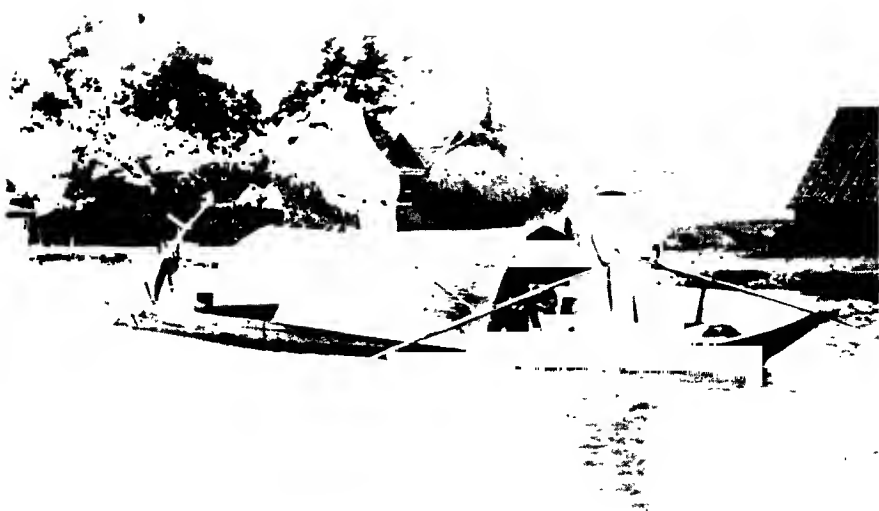


2. Water buffalo are being driven round and round on the sheaves of rice to thresh out the grain. Thailand.

(Both photographs courtesy of Dr. Hugh Popenoe)



1. Bundles of rice are threshed by beating them against the huge basket. Near Chiang Mai, Thailand



2 River boats are used to transport the crop to market in the Central Basin, Thailand.
(Both photographs courtesy of Dr. Hugh Popenoe)



1. Winnowing the grain from the chaff by hand fanning, near Chiang Mai, Thailand.



2. A foot-operated pestle drops on the rice in the container to the right and thus pounds off the hulls — Northeast Thailand
(Both photographs courtesy of Dr. Hugh Popenoe)



1. A herd of the half-wild black scrub cattle being rounded up on the salt flats, near Les-Saintes-Maries-de-la-Mer.



2. The field to the left of the drainage ditch is irrigated periodically to flush out the salt. An untreated field, covered with halophytic plants, to the right.



1. A tractor with cage wheels being used to chop up weeds in a field preparatory to planting rice seedlings. (Courtesy F. Patissier, Syndicat des Ruriculteurs de France)



2. A seedbed for rice seedlings with a natural fence of evergreen trees as a protection against the mistral that so often roars down the Rhone Valley.



1. Laborers from Valencia, Spain, pulling up rice seedlings from the seedbed. They are made up into bundles, then taken to the fields for transplanting.



2. Harvesting was often done by hand a few years ago, but is more and more being done by combine-harvester. (Courtesy of F. Patissier, Syndicat des Riziculteurs de France.)

and other countries of the Far East. This axiom has been undermined in many parts of the world—in Cuba, in France, in Venezuela, and in the United States. The last two are countries of relatively high labor costs. Probably the two most important factors in effecting this revolution are the phenomenal rise in the price of rice, and the dominant role of the machine in the production of that grain. The internal combustion engine has been adapted in certain countries to do most of the work formerly done by a poorly paid, often wretched, labor force. In the United States workers enter the fields on the ground only twice—to prepare them for planting the seed and later to harvest the crop. The operations of planting, fertilizing, and weeding by the application of chemical weedkillers all are done by plane from the air. Yet the greater part of this mechanically produced rice is for export, much of it to the Orient!

To be sure, the problems confronting rice growers vary markedly from country to country. In Valencia, Spain, the rice farmer has an abundance of cheap labor, but little machinery, with its attendant high costs. In the United States generally the rice grower has extremely expensive labor but relatively cheap and efficient machinery for the cultivation of vast tracts. In north Italy both labor and machinery are relatively cheap.

Activated in large part by the food shortages consequent upon the German Occupation (1940–1944), French rice culture in the Camargue has evolved as the result of the coaction of a series of favorable factors, in spite of extremely high labor costs as well as of high prices for machinery.

Rice in the Camargue is perhaps not a “political crop” to the extent that the sugar beet was under Napoleon, but political factors would seem to share honors with technological developments in the responsibility for tracing out the historico-geographic trajectory followed by the Isle de la Camargue. To continue the figure of speech: rice in France was a spent missile, a dud, by 1942, but it ricocheted after that and became airborne, as a result of the coaction of the several factors enumerated above.⁸

SPAIN⁹

In the flood plain of the lower Guadalquivir River vast tracts of land have been reclaimed by the installation of large-scale irrigation works. Some 25,000 acres of once semiarid land have been made pro-

⁸ Crist, Raymond E., *Rice culture in the Camargue*, *Ann. Assoc. Amer. Geogr.*, vol. 50, No. 3, p. 312, September 1960

⁹ Under the auspices of the Social Science Research Council and the John Simon Guggenheim Memorial Foundation, the author also carried out field investigations of rice culture in Cuba (Some notes on recent trends in rice production in Cuba, *Econ. Geogr.*, vol. 32, No. 2, pp. 66–74, April 1956) and in Spain (Rice culture in Spain, *Sci. Monthly*, vol. 84, No. 2, pp. 66–74, February 1957).

ductive in a few years, a cultural landscape created by modern technology and machinery. The whole industry is directed largely by one person, and the area under cultivation is still being expanded. Rice is grown with an eye to the international market; indeed, 30,000 tons were shipped to Japan in 1955.

Rice culture in the plains of the Seville sector is based on a lavish use of low-cost, seasonal laborers from the hill villages, who have no rapport with management and no stake in the land or industry itself. Only the harvesting of the crop is mechanized. Regions of *latifundia* everywhere seem to suffer from chronic unemployment or underemployment, whether as manorial holdings during the Middle Ages, worked by serfs, or as neoplantations today, manned largely by hordes of paid migratory laborers. Andalusia is thus seen to be a region of cleavages, between the hill villages and the plains, between the haves and the have-nots—the few landed and the many landless, most of whom are utterly without hope.

In the *huerta* of Valencia, on the other hand, rice culture, started by the industrious Moors, has been an instrument in the reclamation of dry land and of marsh land. The present cultural landscape has evolved slowly and painfully, step by step, over the centuries, down to the present. In a few sectors rice is grown in large plots on a one-crop basis, but elsewhere it is grown on small plots in a system of interculture, which gives a greater spread of labor than is enjoyed in an area of one-crop farming.

The crop itself is largely for domestic consumption, usually in the form of the internationally famous dish known as *paella Valenciana*, a dish of rice with seafood, meat, or chicken. Rice growing is an integral part of the whole regional economy, a significant factor in the evolution of a closely knit regional unit, socially, linguistically, and economically. Centrifugal political tendencies there may be, but regional cohesion is strong because the cultural landscape has over the centuries been cut to the measure of man.

RICE IN THE TROPICS

In several widely separated sectors of Cuba, soils that only a few years ago were considered poor to worthless are being used for the production of rice. These producing areas, in which the natural landscape has remained unchanged for millennia, are undergoing a rapid transformation. The rapidly evolving cultural landscape in these sectors is due almost entirely to the favorable economic climate induced by the high price of rice.

Although the consumption of wheat has decreased in the traditional wheat-bread-eating countries, owing to the increased use of "protective foods," the consumption of rice in the world increases

steadily and world production of that grain is greater than that of wheat. The grower of rice is almost always sure of a crop because pests and serious diseases are few. Rice is a concentrated form of relatively cheap calories that keeps well and can be easily shipped. It is easily digested and is what might be called neutral in flavor; hence the person accustomed from childhood to consuming rice never seems to tire of eating it. Millions of people of the world practically live on rice alone and are glad indeed if they can obtain each day the few grains of rice necessary to keep body and soul together.

Since many tropical lowland soils can be used for crop production, they will have to be pressed into service as the number of mouths to be fed increases. Fortunately, many of the principles of agronomy which apply to the usual grain crops do not seem to apply to wet or irrigated rice. A soil too infertile to produce any other grain crop will produce some rice if it is well puddled and if the crop can have a few inches of water standing on it throughout the growing season. Lowland rice is the most effective food crop that can be grown on many very poor tropical soils, because it is adapted to wet soils and because even on extremely poor soils it still produces some foodstuffs. Soils of mediocre fertility, which can produce reasonable yields of upland grain crops, if planted to lowland rice, flooded, irrigated, and weeded, can produce about a quarter more of rice grain than of any other grain crops, according to J. Lossing Buck as quoted by Professor Robert Pendleton. Hence it seems inevitable that more and more people of the world, especially those living within the Tropics, will have rice as their basic foodstuff. Wherever it will thrive, anywhere in the world, the growing of rice will probably cover a food deficit more quickly than the growing of any other cereal.

The River Basin Salvage Program: After 15 Years

By FRANK H. H. ROBERTS, JR.

Director, River Basin Surveys, Smithsonian Institution

[With 12 plates]

DURING the closing months of 1944 anthropologists, archeologists, and historians throughout the United States awoke to the realization that the nationwide program for flood control, irrigation, hydroelectric and navigation projects by the Federal Government and the construction of dams by State agencies and private power companies in the various river basins throughout the country were destroying and would continue to destroy many archeological sites. Unfortunately, most of them were in areas where few, if any, investigations had been made and where there was a vast amount of material still to be studied. Because about 80 percent of all archeological remains in the United States are to be found in approximately 2 percent of its area, namely, along the banks of the great rivers and their tributaries, much information pertaining to the aborigines and the history of the Colonial and westward exploration periods of our own people would be obliterated for all time. It was recognized that unless drastic steps were taken to save it, the full story of man's development in the New World could never be written or even adequately outlined. The evidence needed for an understanding of the methods by which people adapted themselves to and overcame adverse climatic conditions, evolved diverse agricultural practices, and devised various types of land utilization would be missing. Furthermore data from which to reconstruct their cultural institutions—social, political, and religious—as shown through settlement patterns would not be available. Without that information it would not be possible to provide a clear picture of American history and the knowledge of how America grew and matured over a period of some 10,000 years. Furthermore, the knowledge needed to understand and evaluate the interplay of forces which produced the various cultures in the New World, the effects each had on the others, and the light they might throw on comparable phenomena

in the Old World, as well as on the relationship of present-day peoples, would be lost.

In view of that situation an exploratory meeting of members of the Committee on Basic Needs in American Archeology of the National Research Council and archeologists stationed in Washington, D.C., was held at the National Research Council in January 1945. Various plans were suggested at that time for starting a program for the salvage of materials from areas which would be inundated or otherwise disturbed by construction activities, but no definite action was taken. As an outgrowth of the discussions, however, an independent committee, the Committee for the Recovery of Archeological Remains, consisting of representatives from the American Anthropological Association, The Society for American Archaeology, and the American Council of Learned Societies, was organized in April of the same year and began a careful study of the problem. During the same period members of the staff of the Smithsonian Institution were preparing a tentative program and discussing the situation with representatives of various agencies engaged in the development of river basin projects. Concurrently the National Park Service, the Bureau of Reclamation, and the Corps of Engineers completed agreements providing for the study of recreational resources of proposed reservoir areas. The original agreements made no mention of archeological and historical remains, but in May of that year the National Park Service indicated that studies of such manifestations would be included in the overall program and that preliminary preparations were being made to that end.

In the late spring of 1945 the Smithsonian Institution and the National Park Service, through the work of the Committee for the Recovery of Archeological Remains and through informal discussions between the Director of the National Park Service and the Secretary of the Smithsonian Institution, became aware of the common goal toward which both were striving. A series of conferences followed which made clear the fact that the Smithsonian Institution and the National Park Service were ready to cooperate fully in any major program for the survey and recovery of archeological remains and that the Smithsonian Institution was willing and prepared to take scientific responsibility for the actual work in the field. Shortly thereafter it was recognized that paleontological materials would also be involved and they were included. During the summer months a memorandum of understanding between the two agencies was drawn up providing in part that the National Park Service would call to the attention of the Smithsonian Institution the locations of all the proposed dams and reservoirs and that the Institution would advise the National Park Service as to the number and importance of the archeological or

paleontological sites located within such areas and would recommend such surveys and other work in the field as might be indicated. In addition, the National Park Service was to notify the respective agencies planning or constructing dams as to the nature and extent of the materials that would be lost if extensive investigations and excavations were not undertaken in advance of the flooding of the reservoirs. The agreement between the two agencies was signed in October 1945, and the Inter-Agency Archeological and Paleontological Salvage Program became an established fact.

OPERATIONS OF THE PROGRAM

The Smithsonian Institution, in order to fulfill its part of the Memorandum of Understanding, shortly thereafter organized the River Basin Surveys as a unit of the Bureau of American Ethnology. The River Basin Surveys was then furnished with lists of Corps of Engineers, Bureau of Reclamation, and other projects by the National Park Service. From those lists it was apparent that such rapid progress was being made in the construction of dams that vital information which in normal times would be recovered through the work of several generations of archeologists would need to be salvaged within a few short years. Information available in published reports and obtained through correspondence with local societies, interested laymen, colleges, universities, and museums indicated which were the most critical places and where initial surveys should be started. It was clear that in many regions the operations would be a race against time.

The Missouri Basin was chosen as the first scene of operations because of its size, the fact that 105 projects had already been authorized and in many cases were under construction, since very little was known about its broader manifestations, and because of its importance to American archeology in general. Justifications for the work in the Missouri Basin were presented to the Bureau of Reclamation by officials of the National Park Service, and a preliminary allotment of funds to start the investigations was transferred from the Bureau, through the National Park Service, to the Smithsonian Institution in May 1946. The funds were to cover surveys in both Corps of Engineers and Bureau of Reclamation projects. In September of that same year an allotment for the work in other areas was transferred by the Corps of Engineers through the National Park Service. The latter, however, was for use only in Corps of Engineers projects outside the Missouri Basin. In the following March the Bureau of Reclamation transferred money to be used for surveys at Bureau projects in the Columbia-Snake Basin. Since that time all the funds for salvage work have been carried in the budget of the Department of the Interior in the items for the Bureau of Reclamation and the

National Park Service. The money for the Smithsonian Institution's activities has been transferred each year by the National Park Service.

The amounts appropriated for the salvage program were increased each year until 1951. There was a progressive reduction in 1952 and 1953 with a sharp curtailment for 1954 and 1955. As a result of the decrease during the two latter years, the program was impeded to such an extent that it was not possible to carry on even a bare minimum of what the situation required. There was some increase for 1956 but the addition was still inadequate. A grant from the Idaho Power Company for work along the Snake River helped the program considerably. In 1957 the situation was much improved and continued so through 1958. For the Missouri Basin there was a sharp drop again in 1959 and 1960 but projects in other areas fared better. This affected the Smithsonian River Basin Surveys more than cooperating institutions, however. Specific appropriations for investigations at the Glen Canyon and Navajo projects in the Upper Colorado Basin and for work in several Georgia reservoir areas went to cooperating institutions. The peak years in the program were 1951, 1952, 1957, and 1958. In 1951 and 1952 there were 17 parties from the River Basin Surveys operating in all parts of the country, while 21 parties from cooperating institutions were busily engaged in field research. In 1955 the comparable figures were 4 for the River Basin Surveys and 7 for cooperating agencies. During 1956 there were 8 River Basin Surveys parties and 4 cooperating ones. The River Basin Surveys had 21 field parties in 1957 and the cooperating institutions 22. The Smithsonian sent out 17 parties in 1958 and there were 37 cooperating projects. The year 1959 saw 8 River Basin Surveys parties at work, while the cooperating institutions had 40. In 1960 the figures to July 1 were Smithsonian 8 and cooperators 41.

During the first 3 years of the program many State and local institutions, colleges, museums, and historical societies assumed responsibility for specific units of various projects in their own region. The entire cost of such assistance was borne by the cooperating institutions. Subsequently, however, there was a change in policy and a number of local institutions signed memoranda of agreement with the National Park Service whereby they were furnished funds to supplement their own in the excavation of sites chosen in accordance with recommendations by the Smithsonian Institution. Such agreements proved beneficial and enabled the cooperating groups to accomplish much more than would otherwise have been possible. There have been 38 cooperating organizations in all and they have accounted for 18 percent of the work accomplished. In addition, the National Park Service in recent years has written a number of personal service contracts for specific investigations of a limited nature.

Throughout the period from 1946 to July 1, 1952, the Smithsonian Institution conducted or generally supervised the archeological and paleontological investigations throughout the various areas, while the National Park Service made the historical and recreational studies. Beginning in July of 1952, however, the National Park Service took over the archeological activities in the Columbia Basin and Pacific Coast areas, in the Southwest including Texas, part of Georgia, and other portions of the Southeast. The Smithsonian Institution concentrated its efforts in the Missouri Basin and in certain areas in Virginia, Georgia, and Tennessee. The Smithsonian Institution, however, has served in an advisory capacity for the projects under the National Park Service, and the results obtained by that agency as well as those of the State and local institutions are being correlated with those of the River Basin Surveys. Because of the lack of funds, work in most areas outside the Missouri Basin, except for a few agreements with local institutions, came to a virtual stop in late 1954. Efforts to obtain additional help from some of the large foundations were unsuccessful. The situation was bettered somewhat in the fiscal year beginning July 1, 1955, by a special appropriation for investigations in the Table Rock Reservoir area in the White River drainage in southern Missouri and northern Arkansas. There were still no funds, however, for many projects outside the Missouri Basin.

The program as originally outlined and which has been followed throughout the 15 years of its existence was divided into four phases: (1) Preliminary reconnaissance or survey of each area where construction was planned or underway for the purpose of locating sites which would be involved and choosing those to be recommended for excavation. This phase includes the preparation of appraisal reports which summarize the archeological and paleontological manifestations observed and contain specific recommendations for future work. (2) The excavation of sites. (3) Processing the collections obtained from the digging, study of the materials, and preparation of scientific reports on the results. (4) Publication of the completed reports.¹

Actual fieldwork got underway in the summer of 1946 and has continued to the present. Surveys have been made in 255 reservoir areas located in 29 States, while 1 lock project and 4 canal areas were also investigated. As a result some 4,948 sites have been located and recorded. The sites recorded by the survey parties represent the whole range of such remains known throughout the United States. They include localities attributable to occupation by some of the early hunting food-gathering peoples, camping places intermittently oc-

¹ A list of published materials pertaining to the Salvage Program is to be found in the appendix to Bulletin 179 of the Bureau of American Ethnology.

cupied by later Indian groups, quarries, bluff and rock shelters, caves giving indications of habitation, villages, large fortified villages, artificial mounds, burial grounds, ossuaries and cairns, and battlegrounds. Associated with many of the various kinds of sites are groups of petroglyphs and pictographs pecked into or painted on adjacent large boulders or the faces of neighboring cliffs. Other sites consist of places of historic interest, such as early trading posts, pioneer forts, and colonial and pioneer villages. In many cases there is a definite correlation between Indian remains and those of the white men, and study of the materials from them undoubtedly will throw helpful light on acculturation problems and the effects of an advanced civilization on primitive cultures. Considerable documentary information is available on the late periods, but in many cases the written records will be clarified and augmented by the archeological evidence. Of the total number of sites recorded, 1,154 were recommended for excavation or limited testing.

As of June 30, 1960, excavations or extensive tests had been made in 487 sites in 54 reservoir basins located in 19 different States. These totals do not include the work of cooperators since 1952, as that information has not been assembled for ready reference. In some of the reservoir areas only a single site was dug, while in others a whole series was examined. At least one example of each type of site found in the preliminary surveys has been investigated. There is still much to be done, however, with respect to the remains of different cultural periods.

EVIDENCES FOR EARLY HUNTING PEOPLES

Among the most significant of the early remains are those excavated in the Medicine Creek Reservoir basin in southwestern Nebraska by the Nebraska State Museum. In that area were three localities which gave evidence that the region was occupied in late glacial times by wandering groups of bison hunters. Some of those hunters, representing two or three different cultural traditions, camped along Medicine Creek and its tributaries on numerous occasions over a fairly long period of time, as demonstrated by the material obtained from intensive digging at three sites. One of them was located on Medicine Creek proper and the other two were on Lime Creek, a small tributary of Medicine Creek. The digging at two of the sites was on a purely voluntary basis by the Nebraska State Museum, while that at the third was under a cooperative agreement with the National Park Service. At the lowest level at two of the sites the materials found indicated that the basic population unit probably was a small group of seminomadic hunters who made bone and stone tools, worked the pelts and hides from animals, and possibly made some form of sewed clothing. Indication of the latter is a series of well-made bone needles

which were collected from the occupation level. The people were primarily dependent upon large game animals for their food, but they also utilized small animals, birds, reptiles, amphibians, shell fish, and possibly insect grubs, as well as roots and seeds, to round out their diet. Charcoal from that level at one of the sites gave a radiocarbon date of $10,493 \pm 1,500$ years before the present. Geologic and cultural evidence strongly indicates that the comparable occupation at the other site was during approximately the same period.

One of the Nebraska sites, the Red Smoke, proved particularly significant in containing eight distinct occupation levels. Materials from several lying just above the oldest occupation level also represented a hunting economy, but they are related to a widespread culture which has been found as far south as western Texas and north and west in Wyoming and the Dakotas. Charcoal from the top level in that particular horizon has given a carbon-14 date of $8,862 \pm 230$ years before the present. The bulk of the material, however, antedates that particular level and indicates that the culture was present in the area during the period from about 9,000 to 10,000 years ago. The other site where the oldest level was present also contained a later horizon with some materials comparable to those found at the Red Smoke site. Evidence for the economy at that period was for a continued dependence on hunting but with a change to smaller types of animals. The large bison apparently were not present in the area during that interval, and there may have been a change in climatic conditions which caused them to move elsewhere. A radiocarbon date of $5,256 \pm 350$ was obtained from charcoal from that level. The paleontological material from the sites is proving useful in a study of the rate of evolution which has taken place in various animal forms during the past 10,000 years. In some cases there apparently has been no change, while in others there are marked differences between the older and the more recent forms. Another important factor in the evidence pertaining to the oldest occupation in two of the sites is that the materials were found in a specific geologic context. The latter indicates the Two Creeks interval of the late Wisconsin glacial stage.

Belonging to the same broad cultural horizon as the older levels at Red Smoke was a site in the Angostura Reservoir basin in South Dakota. It was excavated by a party from the River Basin Surveys. Artifacts found there indicate a heavy reliance on hunting although there may have been some use of ground seeds and nuts. Bones, however, are virtually nonexistent in the deposits, which may be the result of a high gypsum content in the soil that caused rapid disintegration. A few of the implements from that location indicate relationship to some of the forms from the Red Smoke site, others to some occurring

in early localities in the Pinto Basin in the Mohave Desert in southern California. Charcoal from the site has given a radiocarbon date of $9,380 \pm 500$ years before the present. This information helps in determining the approximate age of sites in Wyoming where similar implements were found in association with bison bones, but which contained no evidence bearing on their antiquity.

Evidence for another hunting group was obtained from the Lind Coulee in the State of Washington. The Lind Coulee is one of the westernmost of the scabland channels eroded by waters from melting Late Pleistocene glaciers. It is located near the southeastern end of the O'Sullivan Reservoir, and evidence of human occupation was found along its banks during the preliminary surveys of the reservoir area. Inasmuch as the Lind Coulee is to serve as a channel for the runoff water from the irrigation project connected with the O'Sullivan Reservoir, salvage operations appeared to be warranted at that location. The first digging done there was by a party from the State College of Washington in cooperation with the University of Washington and the River Basin Surveys. Subsequent excavation was by the State College of Washington under a cooperative agreement with the National Park Service. The materials found indicated that the people were dependent in the main on hunting, with bison as the primary source of food. In addition, however, ducks, geese, muskrat, and beaver were also killed. There was no evidence whatsoever of the use of fish, although the location of the site on what had been the shore of a lake or stream suggests that some fish may have been taken. The culture represented is not particularly exceptional in its characteristics and probably is attributable to a rather widespread group in that general area. Radiocarbon dates obtained from charcoal from the occupation level are $9,400 \pm 940$ and $8,518 \pm 460$ with a weighted average of $8,700 \pm 400$ years before the present.

LATER CAMPSITES

The remains of a number of simple campsites of much later date were investigated in several reservoir areas. The information obtained from them was not as complete as might be desired but it does tell something of the habits and way of life of the people who formerly tarried there. Because such places were occupied only for short periods, or at brief recurring intervals by hunting parties, the amount of material left is small in comparison with that at locations where more permanent villages were erected. At campsites there are no traces of dwellings or habitations. Highly perishable brush structures or skin tents may have served as temporary shelters. At some locations there are circles of stones, usually called tipi rings, that are thought by many to have been used to anchor the bottoms of tents.

If such were the case, we may conclude that habitations of that type were used. However, there are those who maintain that the rings were for other purposes, and excavations thus far have not provided the answer. Campsites for the most part are characterized by scattered hearths containing charcoal and ashes, and by refuse deposits consisting of bits of charcoal, ashes, cut and broken animal bones, chipped-stone debris, sporadic potsherds and occasional restorable vessels, and other rubbish. A number of sites of that type were excavated in the Jamestown and Garrison Reservoir basins in North Dakota, the Angostura Reservoir area in South Dakota, and the Boyesen and Keyhole Reservoirs in Wyoming. They were found to represent a number of different periods. In some cases they dated from a millennium to a few hundred years before the beginning of the Christian Era. Several fall in the early part of that period. One, in the Garrison area, was several feet below the remains of an earth-lodge village. Other examples appeared to belong to late prehistoric times, while a few represented an early contact period as was shown by the presence of trade beads and fragments of metal. The potsherds occurring in some suggested that the camps had been occupied by hunting groups from permanent villages along the main stem of the Missouri. Since they obviously antedated the introduction of the horse in the Plains, they indicate that the people at times made long journeys on foot in search of, or following, game. In the main the materials from the campsites show the progress of the people from nomadic to semi-nomadic life with changing types of implements and differences in food habits resulting in part from climatic fluctuations, shifting feeding grounds for game, and the development of agriculture in the more permanent settlements along the Missouri proper. It is interesting to note that bones from the trash heaps show that in the earlier stages bison were the main meat supply, then smaller animals and, finally, bison again.

ROCK SHELTERS AND CAVES

Rock shelters and caves have been excavated in a number of areas. Perhaps the oldest materials from such locations were obtained from two shelters in the Keyhole Reservoir basin on the Belle Fourche River in Wyoming. Both of those sites contained stratified deposits showing several periods of occupation. The bottom level in each correlated with an open campsite in the same area which contained materials representing an Archaic hunting people who were in the region following the period of the early hunters but antedating the later and better-known inhabitants. Charcoal from the bottom level of one of the shelters gave a radiocarbon date of $2,790 \pm 350$. The artifacts from the several layers in the deposits show a progression in imple-

ment types and record a possible modification of hunting and butchering techniques through the change in the forms of projectile points and other stone tools. The stratigraphic materials also make it possible to place a number of the open sites in their proper relative chronology. The top level in one of the shelters contained some potsherds from vessels of the so-called Woodland type which are significant because they extend much farther westward the known range of that kind of Indian pottery and show that the peoples living in the area at that time either were under the influence of tribes located at a considerable distance to the east or possibly had trade relations with them. The material from the shelters also provides the basis for correlating a number of important sites scattered between that portion of Wyoming and central Nebraska.

Three shelter-cave sites were excavated at the Whitney Reservoir on the Brazos River in Texas. One, locally known as Pictograph Cave because of a series of symbols painted on one wall in red and yellow ochre, gave evidence of two definite periods of occupation. The top level seems to have been pre-Columbian in age although quite late in the prehistoric period. The lower level suggests that it was prior to approximately A.D. 1200 but it is not possible to say how long it was before that date. There were distinct differences between the upper and lower levels and good evidence was obtained concerning changes in food habits and population density during the two occupations. Since Pictograph Cave was a dry shelter, vegetal remains were preserved in all levels. It is curious, however, that no perishable artifacts, such as matting, basketry, or cord, were found in either horizon. Such objects undoubtedly were made and used by the Indians in that area, and it is difficult to explain why there was no evidence of them when plant materials were abundant and so well preserved. The cultural material from the early occupation is similar in many respects to that from what has been called the Round Rock Focus in the central Texas region. The second or last occupation has not yet been correlated with other known remains although it may be possible eventually to determine its relationship. Not far from Pictograph Cave was a location called Buzzard Shelter. Digging there revealed that it also had been occupied at two different periods and there was general similarity between the sequences in it and at the first location. Some definite differences in artifact types appeared, however, and it seems likely that the material in the second site was left by somewhat different cultural groups. The specimens from the lower level at Buzzard Shelter probably are attributable to a fairly early complex and indicate a hunting-gathering form of economy. The upper-level materials correlate rather satisfactorily with what has been named the Toyah Focus in central Texas. The

third location, which was much larger than the other two and was known locally as Sheep Cave, contained cultural sequences which follow in general those at Pictograph Cave and Buzzard Shelter. Sheep Cave contained, in addition to the material culture remains, five flexed burials. Studies on the skeletons have not been completed but it is expected that they will give a good indication of the relationships of the people. As a whole the information and specimens from the three sites give a much better understanding of the archeology of that part of Texas, and when considered in conjunction with the results of other investigations in the Whitney Reservoir basin should provide a satisfactory story of aboriginal activity in the area.

VILLAGE REMAINS

Most of the excavations made by River Basin Surveys parties and cooperating institutions have been in village remains, the largest and most extensive being in the Missouri Basin. At the Medicine Creek Reservoir in western Nebraska, where the early hunting sites previously described were located, 8 village sites were excavated by a party from the River Basin Surveys, and 14 house remains in 6 different sites were dug by a party from the Nebraska State Historical Society. Six of those investigated by the River Basin Surveys represent what is known archeologically as the Upper Republican Aspect, while the other two were a variant of the Woodland Culture which was widely distributed over areas farther east. The Upper Republican sites showed that the people of that culture usually built their roughly rectangular houses in clusters of two to four with the groups frequently located some distance apart. Because of that practice, there is a question as to whether they might not more properly be called family communities rather than villages. Often it was difficult to determine where one village stopped and another started, although there were examples indicating that villages at times might contain as many as 18 to 35 or 40 houses.

Artifacts found in association with such houses consist of stone and bone implements, objects of antler, potsherds and restorable pottery vessels, and occasional shell ornaments. In the storage pits were charred kernels of corn, corncobs, charred nuts, squash seeds and sunflower seeds, as well as bison bones, fish bones, crayfish, and fresh-water mussel shells. The people who lived in such communities obviously depended primarily on agriculture with hunting a secondary occupation.

The two village sites where the Woodland variant occurred showed that the house type was not as well developed as that of the Upper Republican Culture. The houses were grouped fairly closely in clusters of four to six. The superstructure appears to have been rather

flimsy although fairly permanent, and probably had a roof of brush with a grass and bark or skin covering. The floors were 12 to 18 inches below the ground level and formed a circular to oval basin. They had no well-defined pit for domestic fires, which apparently were lighted on the floor near the center of the enclosure. The implements from the house remains and middens do not exhibit as great variety as those from Upper Republican sites and in the main were those used for hunting and gathering. Objects made of bone and bone beads were common, and shell was used for making ornaments. Hunting and food gathering were the main means of sustenance. Deer and antelope bones were plentiful, with some of bison, although not so numerous. The use of small game was evidenced by the large numbers of bird bones scattered through the refuse deposits. There was no evidence of horticulture, either direct or inferential. Occupancy of the Woodland villages appears not to have been as permanent as in those of the Upper Republican Aspect. It seems that the Woodland sites must be older, but no definite stratigraphic evidence was found to show that such was the case. On the basis of knowledge about the Woodland Culture elsewhere, the Medicine Creek remains have been dated tentatively as falling within the general period A.D. 500 to 1200, while the Upper Republican remains are believed to date from about A.D. 1200 to 1500. Thus far it has not been possible to correlate the Upper Republican remains with any of the known tribes, such as the Dakota, Pawnee, or Comanche. That may be done later.

In the Fort Randall Reservoir area in South Dakota a number of different types of village remains were excavated. At the Oldham site on the east bank of the Missouri River, approximately 10 miles west of the town of Platte, River Basin Surveys parties found evidence for three occupations. The first group to live there presumably erected simple dwellings, although traces of them are meager. The people did, however, make extensive use of large cache pits for storing their surplus food. Subsequently a series of earth lodges was built and the village was enclosed by a palisade. The third stage also represented an earth-lodge village which was fortified by an encircling palisade with a moat. In both communities the houses were circular in ground plan. The relationships of the original group have not yet been determined, but indications are that the culture was influenced by or stemmed from some of those farther south and east in the Nebraska area. The intermediate period shows affiliations with the so-called Great Oasis Aspect in Minnesota. The final period possibly represents an outgrowth from the middle period with an admixture of cultural elements from groups farther north along the Missouri River. When studies on the data obtained at that location have been completed, there no doubt will be good information pertaining to the



1. Excavating Paleo-Indian site in the Angostura Reservoir area.



2. Digging fossils in the Garrison Reservoir area.



1 Using road-building equipment to clear overburden from village site.



2 Small farm tractors expedite removal of fill from house depressions.



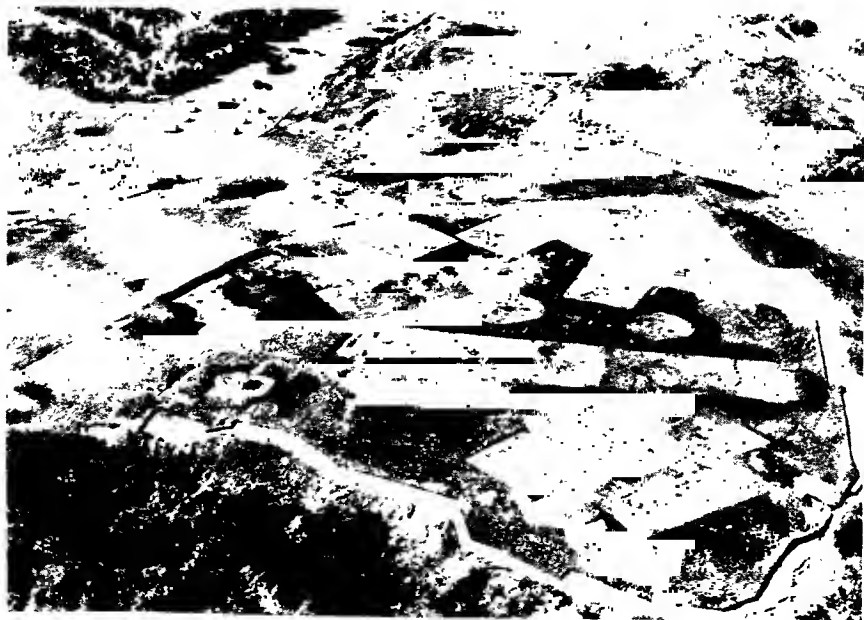
1. Aerial view of fortified village site. Remains of encircling moat are clearly visible. Portion of site above river has eroded away.



2. Tracing palisade for fortified earth-lodge village. Holes in outer row indicate line of palisade.



1. Remains of long-rectangular house, Oahe Reservoir, South Dakota, with remains of circular earth lodge above it. C-14 date for rectangular house was 800 ± 200 years (A.D. 1156).



2. Earth-lodge village site on top of small butte in the Garrison Reservoir, South Dakota. Locations of houses shown by post holes. Village had encircling palisade at edge of butte.



1. Excavating portion of circular house, most of which had already been washed away by rising waters of the Oahe Reservoir.



2. Bison bones found in a slaughtering area near a village site.



1. Excavating house remains along the Columbia River



2. Clearing house floors in the Alatoona Reservoir area in Georgia. Stakes indicate positions of wall posts.



1. Stone scrapers and arrowheads from Missouri Basin.



2. Pottery vessels from Macona Reservoir area in Georgia.



Sequence of aboriginal pipe forms from John H. Kerr (Buzes Island) Reservoir in southern Virginia. Oldest type at top.



1. Primary, log-covered Arikara burials in South Dakota.



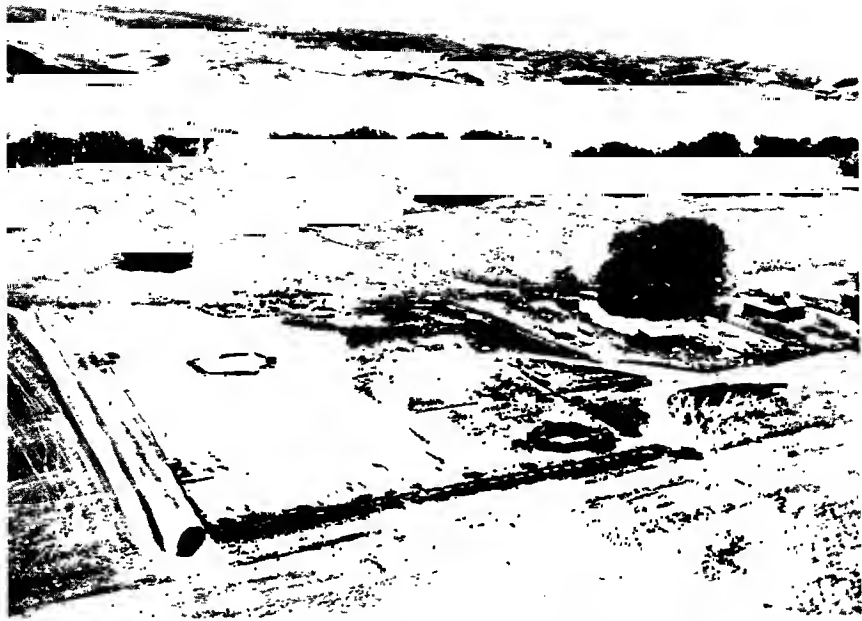
2. Excavating double burial at the Sully Site in Oahe Reservoir area.



1. Uncovering bison remains on ground level beneath low mound in North Dakota. Darkened area in right center of picture indicates location of human grave pit.



2. Stockade area of Fort Berthold II as seen from the air. Locations of bastions appear at lower left and upper right corners. Like-a-Fishhook village house pits are at the left.



1. Aerial view of excavations under way at Fort Pierre II, South Dakota. (Photograph by H. Carlson, U.S. Corps of Engineers).



2. Clearing old surface of area within stockade at Fort Pierre II.



Types of objects found at Fort Pierre II. Mainly personal and military items are represented.

growth and development of the fortified village type of community in that district. Indications are that the three occupations at the Oldham site were in the period from A.D. 1500 to 1700. The economy of the people was primarily based on horticulture supplemented by hunting and some fishing.

Farther north in the Fort Randall area, about $3\frac{1}{2}$ miles below Fort Thompson, also on the east side of the Missouri River, the University of Kansas under an agreement with the National Park Service excavated a large site known as Talking Crow. At that location evidence was found for five occupations. The latest was Siouan dating from shortly after the Civil War. Prior to that was the last occupation by earth-lodge-building people, probably the Arikara. They lived there at the time when European trade goods were beginning to appear in the area, probably about A.D. 1700 to 1725. The preceding occupation was by an ancestral group and is believed to have dated from about 1600. Below that the occupation level was definitely prehistoric and its cultural affinities seem to be widespread, extending into Nebraska and Kansas. The period indicated is about 1500. The first inhabitants of the site belonged to a pre-earth-lodge group whose affiliations have not yet been completely identified; they probably were prior to A.D. 1000. The next to the last occupation appears to correlate culturally with the final occupation at the Oldham site, although it may be somewhat later chronologically. The material from Talking Crow provides interesting information on the changes which took place in the Indian culture after white influence first reached them and then became increasingly predominant. The Fort Randall Dam was closed in the summer of 1953, and all the sites in that reservoir basin are now under water.

Upstream from the Fort Randall Reservoir basin is a second large project, the Oahe Reservoir, the dam for which is approximately 6 miles above Pierre, S. Dak. It was closed in July 1958, and the lake formed by the impounded waters will be about 265 river miles in length. The area to be flooded contains the greatest concentration of aboriginal remains in the entire Plains area. There were literally hundreds of earth-lodge villages, numerous temporary camps and other occupation areas scattered along the terraces on both sides of the stream in that area. The survey parties located 318 sites while going over the area to be flooded. Some of them are the largest and most impressive archeological locations in the United States. Thus far only a few have been excavated, but the results obtained have added greatly to the knowledge of aboriginal developments along that portion of the Missouri. They also emphasize the great wealth of material which still remains to be investigated. The excavation at two of the sites, the Dodd and the Philip Ranch, have been de-

scribed in detail in Bulletin 158 of the Bureau of American Ethnology. The remains of several fortified villages were excavated by River Basin Surveys parties and by parties from cooperating institutions. They represent several different periods but all are relatively late in the precontact period. Extensive digging also was done at the Sully site which was the largest of the earth-lodge village sites in the Missouri Basin. Two different periods of occupation were found there but they probably fall in the period between A.D. 1600 and 1750. Reports on the investigations in these large sites have not yet been completed.

Farther upstream in the Garrison Reservoir area, N. Dak., survey parties located 153 sites. They consisted for the most part of the remains of winter villages which had been located on the river bottoms, earth-lodge villages situated on terraces or butte tops, scattered small campsites, and occasional groups of stone circles of the debated tipi ring type. In spite of the extensive remains present in the area, no excavation work had been done there before 1950. During that season the River Basin Surveys and the State Historical Society of North Dakota began investigations in several of the more important sites. That work was continued each season through 1954, being augmented in the summer of 1951 by a party from Montana State University. River Basin Surveys parties excavated in several large village sites of relatively recent date. One of them, called Rock Village, on the right bank of the river about 9 miles above the dam, was occupied by a group of Hidatsa for about a decade from the late 1820's to 1838. Originally it had consisted of some 25 to 30 closely spaced lodges and had been fortified by an encircling ditch and palisade. Later about 10 new lodges were built and a portion of the original ditch and palisade was abandoned and a new segment constructed to include the additional dwellings. The remains of 13 earth lodges, several sweat lodges, 60 cache pits, and a number of other features were excavated. It was found that the houses had been circular in form, averaging somewhat more than 40 feet in diameter, and followed the general type of construction in which there was a central rectangle and series of outer support posts forming the framework for the superstructure.

Most of the artifacts obtained from the digging were of Indian manufacture, but materials obtained through trade with the whites occurred in considerable quantities. The main reliance of the inhabitants at that period still was on products of native handicraft although objects of European manufacture were rapidly being adopted. Of particular interest was the finding of seashells derived from the Pacific Coast and a number of pieces from steatite vessels. The latter objects, as well as the shells, definitely suggest trade relations with more westerly tribes and may well have reached that part of North Dakota by

the aboriginal trade route which followed up the Columbia and down the Missouri River. Rock Village presumably was the most northerly of the fortified earth-lodge communities belonging to the period immediately preceding the replacement of aboriginal material culture by trade goods obtained from the white man and is of particular importance for that reason. The cause for its abandonment is not yet clear, but it presumably pertains to the disturbed conditions resulting from the intrusion of other tribes into the area at about that period.

Approximately 12 miles above Rock Village on the opposite side of the stream, portions of Like-a-Fishhook Village, which had been built in the 1840's by the Hidatsa and Mandan and to which some of the Arikara moved in 1862, were excavated during three summer field seasons by a party from the State Historical Society of North Dakota in cooperation with the National Park Service. While there is considerable documentary information pertaining to that village, it was thought that the possibilities for coordinating archeological, ethnological, and historical data were such as to justify the excavations. In addition, two trading posts, Fort Berthold and Fort Atkinson (Fort Berthold II), had been located there and it seemed likely that useful information on the process of acculturation would be obtained from a careful study of the village remains. From the excavations it is evident that at about 1845 the village was still largely Indian in orientation and in material culture. Bows and arrows and the buffalo lance were still in use. Twenty years later most of the dwellings were still earth lodges but the objects of daily use were largely of white manufacture. Rifles, pistols, and shotguns were the principal weapons. By 1872 log cabins were replacing the earth-lodge type of dwelling to such an extent that there were 97 cabins and only 78 earth lodges. In succeeding years the shift continued until eventually only log cabins were erected. During the course of the excavations there, the field party uncovered the floors of 18 earth lodges and two log cabins, traced the line of the palisade which had been erected around the village, and uncovered the remains of both trading posts. Fort Berthold II was dug by a River Basin Surveys party, while Fort Berthold I was a cooperative project between the Surveys and the State Historical Society of North Dakota. With the coming of more peaceful times and the allotting of lands on the reservation, the Indians began to scatter, and by 1890 Like-a-Fishhook Village was virtually abandoned.

In other parts of the country, village remains yielded useful data, but in most cases the structures were found not to be as well developed or substantial as those along the Missouri. In the Columbia Basin, village sites were excavated in the McNary, O'Sullivan, and Chief Joseph Reservoir areas. In general the evidence showed that many of the structures were circular to oval in form with diameters ranging

from 25 to 40 feet. Such houses were grouped in clusters along the terraces above the river. Little was found to indicate the type of superstructure erected for the dwellings. For that reason it has been supposed that the Indians took with them the main supports from the structures when they moved from place to place. On the basis of knowledge about later houses in the area, it would seem that the dwellings probably consisted of a framework of poles to which branches or mats were lashed. The poles were not embedded in the earth, but some stability was obtained by heaping dirt against the outside walls. The remains of several long oval or rectangular dwellings probably represent so-called "mat houses" which were a form of multifamily dwelling during the historic period in that area. The oval forms found in the McNary Basin agree closely with the descriptions of such houses obtained by investigators working among the Umatilla Indians. Most of the villages investigated along the Columbia were occupied just prior to the coming of the white man or at the contact period. None of the sites excavated gave indication of having been inhabited for any length of time after the visit of the Lewis and Clark Expedition.

In the Terminus Reservoir area on the Kaweah River in Tulare County, Calif., a River Basin Surveys party uncovered the remains of an interesting small village. Trade materials present at the site make it possible to date the village at about 1850. The results of the excavations are significant in that they provide an opportunity to study the material culture left by people who occupied the region in historic times and about whom there is a fairly complete ethnographic record. Items of material culture previously known only through tradition are now represented by actual objects. Information on other village types was obtained elsewhere in California by the Archaeological Survey of the University of California, at Berkeley, which carried on excavations in the Pine Flat, Isabella, and Monticello areas under agreements with the National Park Service.

Two pre-Spanish pueblos, Te'ewi and Leaf Water, in the area of the proposed Abiquiu Reservoir in the Chama Valley in New Mexico were partially excavated by the Department of Anthropology of the Museum of New Mexico under an agreement with the National Park Service. The period represented by both pueblos covers the interval A.D. 1250 to 1500. During that time the Pueblo occupation in the Chama Valley was established, reached florescence, and receded. Considerable information obtained on cultural developments at the two villages helps to explain subsequent Pueblo activities in the Rio Grande Valley below the Chama area. One interesting result of the excavations pertains to the presence of materials which show trade relations with peoples in the central and southern Plains areas. It is

evident that there was considerable contact between the inhabitants of the Chama Valley and Indians from South Dakota, Nebraska, and the Texas panhandle in the 14th and 15th centuries. Certain features which previously were somewhat puzzling in the eastern Pueblo villages can be fully explained now from the evidence obtained during the salvage operations. Also, the source of some southwestern traits among certain of the Plains tribes now becomes clear.

Two River Basin Surveys parties excavated in 11 sites and tested 19 others in the Allatoona Reservoir Basin along the Etowah River near Cartersville, Ga. A number of the sites involved village remains, some of them well-developed communities, and a few of a rather rudimentary nature. As a result of the digging, evidence was obtained for a cultural sequence of 10, probably 11, different stages extending from the historic Cherokee of about A.D. 1755 back to a period when hunting and food gathering comprised the basic economy of the people. Some of the villages in the Allatoona area were fortified, but they represent a much earlier date than those in the Missouri Basin. During the time when the River Basin Surveys parties were working in the Allatoona area, the University of Georgia as a cooperative contribution excavated the remains of a large earth lodge and its associated midden deposits. Three houses identified in the accumulation of debris represented successive groups in the series established by the River Basin Surveys. Useful data obtained there pertaining to the various pottery types for the different stages contributed much toward making clearer the ceramic picture for the area. The results from all the digging in the Allatoona Basin, which is now completely flooded, have done much to establish a detailed story of aboriginal culture growth in northwest Georgia and adjacent areas.

EXCAVATIONS IN MOUNDS

Thus far there has not been much digging in large artificial mounds because the available funds have been insufficient to support projects of a nature requiring large groups of workmen and an extensive program of operation. A good start in large-mound work has been made by the University of Georgia, however, with excavations getting under way in 1959 at the Mandeville site in the Walter F. George Reservoir area on the Chattahoochee River, Alabama-Georgia. Test excavations were made in two mounds in the area flooded by the Buford Reservoir, also on the Chattahoochee River in Georgia. Neither mound had been recorded previous to the present surveys. One of them gave evidence of having been erected over a small natural knoll. The mound appeared to represent a relatively late and previously unrecognized cultural complex which was pre-Lamar in age. The cultural complex designated Lamar in the Georgia area is believed

to have been a part of the widespread period in the Southeast known as Temple Mound 2 and which has been correlated with the Creek-Cherokee peoples. It is dated at approximately A.D. 1450 to 1700. The Buford Mound had the outlines of a small square house on its summit. At one end inside the structure there had been a bench or a throne, and it is supposed that the remains were those of a small ceremonial structure. The other mound was at first believed to be one of the oldest artificial structures thus far discovered in Georgia and to have belonged to the Burial Mound 1 horizon postulated as having occurred from A.D. 700 to 900. Subsequent work there, however, demonstrated that it actually was the remnant of a natural levee built up by the river. There were traces of aboriginal occupation in the deposits which indicated that the material belonged to what has been called the Forsyth period of approximately the dates indicated. There were other mounds in the area but they went under water before they could be tested. Excavations were also made at the Chauga Mound in the Hartwell Reservoir area by the University of Georgia.

Excavations have been made in burial mounds in several different areas, two of them at the Jamestown Reservoir on the James River in eastern North Dakota. The remains of 20 secondary burials were found in a series of pits in various levels in the first mound. The bodies of the individuals represented had been exposed on platforms or in trees for a sufficient period after death to permit the decomposition of the flesh. The skeletons had then been collected and placed in pits in the mound. As additional interments were made, the size of the mound grew through the piling on of sufficient earth to protect the graves. In some cases there were copper jangles or ornaments accompanying the bones, and several bison skulls, probably with ceremonial significance, had been placed between some of the grave pits. The second mound was considerably smaller and only five secondary burials were found in it. They also were associated with bison skulls but had no accompanying mortuary offerings. Excavations in three mounds south of Fort Yates, N. Dak., during the summer of 1960 showed a similar association of human remains and buffalo bones for the Oahe area. These burials appeared to be of an earlier period, however.

There were other forms of burial besides that of placing the remains in a mound or below a mound. In some cases the body was put in a simple grave shortly after death. In others there were single secondary burials, and occasionally a number of secondary interments were made in large ossuary pits. Examples of the simple primary form of burial were excavated at two sites below the Oahe Dam in the area of the outlet channel. Others were dug at some of the large village sites upstream. The Sully site yielded the remains of 224 individuals. Similar interments were investigated along the

Columbia River, in California, and various areas in the Southeast. The skeletal remains showed that several different methods of placing the body were followed. In most cases they were in a contracted position with the knees drawn up and the arms folded across the chest. There apparently was no preference with respect to the side, as some were on the right side and others on the left. A few were lying face downward. There seemingly was no particular preference for the orientation of the head. Some of the graves contained mortuary offerings, while others did not. The grave furniture consisted of pottery vessels, bone and stone implements, shell, and in late horizons, glass beads, and, depending on the locality, various forms of shell ornaments.

An interesting type of ossuary pit occurs in the Republican River drainage in south-central Nebraska and northern Kansas. It has been called "Shell-bead Ossuary" because of the large number of beads made from fresh-water and marine shells which were used as mortuary offerings accompanying the interments. In most cases the human remains found in such pits represent secondary burials, but occasionally a primary interment is present. One good example of such an ossuary was excavated by a River Basin Surveys party in the Harlan County Reservoir area in northern Kansas. Because of the nature of the remains it was difficult to determine the total number of individuals represented. Skulls were few in number and in most cases were in a poor state of preservation, being thus of little help. From a study of the individual bones and a count of the mandibles present, it was apparent that not less than 61 people were represented. Of that number 56 could be identified with reasonable certainty, and in that group 25 were infants and children while 31 were adults ranging from 25 to 55 years of age.

The large number of finished disk beads as well as those in various stages of manufacture which were scattered among the bones and throughout the fill in the ossuary pit probably had been in the body bundles at the time of their primary disposal and were gathered up along with the other remains when the secondary interment was made. In addition to the beads there were also shell pendants of varying shapes, bone implements, and some stone tools. The few potsherds present definitely indicate a Woodland relationship. Charcoal and twigs from the pit throw interesting light on the vegetation in the district and have provided a carbon-14 date. Dr. W. F. Libby, then at the Institute of Nuclear Studies, University of Chicago, tested some of the charcoal and reported in May 1954 that the age of the material was $1,343 \pm 240$ years before the present or A.D. 611 ± 240 years. That date indicated a somewhat earlier period for Woodland materials in the Plains than had been previously estimated and also suggested that pottery-making appeared in the Central Plains several

centuries earlier than most people have believed. The wood samples from the ossuary show that the environmental setting at that time was essentially the same as now. Except for probable wet and dry cycles, the Indians of a thousand years ago in that area apparently lived in surroundings quite comparable to those of today.

A series of burials in plank-lined cysts was excavated on the Columbia River in the McNary Reservoir basin. In one cemetery adjacent to a village site 50 such graves were found. Funerary offerings accompanying the skeletons consisted of both native artifacts and trade goods. Colonial uniform buttons made as early as 1715 came from a number of the graves, and since there was no evidence of firearms, the use of which began in 1811 in the area, it seems likely that the planked cysts belong in a period slightly after 1750 and prior to 1810. The skeletal material recovered there is significant because it represents the best available series for the study of the physical characteristics of the people living in that district. Because it also represents a single closely dated sample, it is particularly useful. Of the remains of 57 individuals recovered, 37 were adults, the remainder children and infants.

Farther up the Columbia River in the various reservoir areas studied by River Basin Surveys parties, it was found that the main form of burial was in rock cairns. Little information could be obtained from such sites, however, because most of them had been disturbed by curio hunters who had taken all the funerary offerings and scattered and broken the bones so that they were of no value for physical anthropological studies. Rock cairn burials also were found in several localities in the Missouri Basin.

HISTORIC SITES

Work in historic sites has not been as extensive as that in aboriginal remains. However, a number of interesting excavations carried on in various parts of the country have yielded considerable information concerning certain periods. The most extensive investigations of that nature have been in the Missouri Basin. In the Garrison Reservoir in North Dakota digging has been done at the location of one military post, which subsequently became an Indian school; at a site which combined both trading and military occupations, and subsequently an Indian agency; and at three trading-post sites. The military post was Fort Stevenson which was located some distance up the Missouri River from the present city of Bismarck. It was a typical frontier post and was built to keep the river open for navigation and to protect the Fort Berthold Indians from the Sioux. It also was one of the main points on the overland mail route from St. Paul to Montana. Although the actual antiquity of the fort is relatively slight,

it represents the first permanent occupancy of that section by the whites and played an important part in the settlement of the area. The fort was started in 1867 and was completed late in 1868.

The work here uncovered interesting evidence concerning the method of construction used in the various buildings, as well as a good series of objects representing items of everyday use, which give a good picture of the kinds of military equipment and household goods that were in favor at that time along the frontier. Many of the larger buildings had been constructed from adobe bricks made on the site by soldiers. According to tradition the bricks were manufactured under the direction of an Indian woman, possibly from the Southwest, who was the wife of one of the soldiers, although this has not yet been substantiated in the documentary records. Several of the buildings had been destroyed by a fire which burned some of the bricks and thus preserved them. In all respects they appear quite similar to the adobes made and used by the Indians and Spanish Americans in the Southwest. There is no knowledge of adobe bricks elsewhere on the Upper Missouri, and their manufacture apparently did not spread from Fort Stevenson. In some of the other buildings the bricks were definitely not of local origin but had been shipped upriver from St. Louis. Fort Stevenson was abandoned as a military post in 1883 and was taken over by the Bureau of Indian Affairs for use as a school. It served in that capacity until 1894, when a new school was erected on the Fort Berthold Reservation farther upstream and to the west. It is interesting to note in passing that when the archeological work was started, no single structure of the military period survived above the ground, even in ruins. Most of what remained of the buildings had been removed for use in later construction and much of the area had been leveled. The materials recovered in the excavation also abundantly record the school period and reveal the things that were in common use by the pupils and teachers during those years. By and large much was learned from the excavations at Fort Stevenson and there is now greater knowledge about it and the general nature of the days when it was occupied than could possibly have been obtained only from the recorded documents.

In previous pages mention has been made of the work done at Like-a-Fishhook Village and the adjoining Forts Berthold I and II. In contrast to the case of Fort Stevenson, the documentary record of earlier years in the Fort Berthold area leaves much to be desired. Consequently, archeological work in historic remains there was of greater importance than that at Fort Stevenson. The site of Fort Berthold II was the first to be excavated, and the remains of Fort Berthold I were not discovered until after considerable work had been done in the Indian village which was located between the

two forts. As a matter of fact, part of the Indian village had been built over the ruins of the first fort and had completely obscured them until they were uncovered by the digging in Indian house remains.

There is some question concerning the date of the original construction of Fort Berthold I, and the only existing records do not help to solve the problem. According to some accounts the original fort was built in 1842, while others indicate that it may have been 1845. There is also some question as to whether the Indian village was constructed and occupied first and the trading post was erected subsequently, or if both were being built at the same time. However, evidence obtained in the field would seem to suggest that the Indian village probably was there first. Then a trading post called Fort James was opened by James Kipp, presumably in the early 1840's. Subsequently Kipp either moved away or disposed of his interests to the firm of Pierre Chouteau, Jr., often referred to by the name of its predecessor the American Fur Company, because the latter, with the assistance of the Indians, began to build a stockaded post on the north side of Like-a-Fishhook Village which by 1846 had become known as Fort Berthold. How extensive Kipp's buildings may have been or where they were located is not known. They may have been on the site of, and have been incorporated in, Fort Berthold I, but the new traders unquestionably erected much of the post as it was known in subsequent years. Kipp returned there later and for a time was in charge. Fort Berthold I played an important part in the native-white contacts in the area and helped to fix the patterns of the relationship between the two peoples. It was during the period of its activity that much of the aboriginal culture underwent the change from "native" to "modern." A joint party from the River Basin Surveys and the State Historical Society of North Dakota conducted excavations at the site, during which the entire palisade was traced and the remains of a number of buildings were located and uncovered. The post appears to have been constructed almost entirely of timber, probably for the most part hand-hewn square members in the dwellings and storehouses and simple unhewn poles in the stockade itself. The only timber available locally in sufficient quantity for use in such construction was cottonwood, and despite the soft and short-lived nature of that wood, it seems to have been used throughout, as the excavations produced virtually no evidence of any other varieties of wood. Various examples of the kinds of hardware used in the construction were recovered along with a variety of nails and some window glass. The lack of traces of lime mortar suggested that the insides of the buildings were not plastered, and the small amount of window glass indicates that they may not

have had many openings. Some of the items found consist of goods employed in the Indian trade, others pertain to the subsistence of the whites and Indians at the fort, including household utensils and personal articles. The Indian trade goods are particularly useful in establishing the type of things being used for that purpose at a specified time. When similar objects are found in Indian sites for which there is no record, it is possible to correlate them with that particular period. Fort Berthold I was destroyed by fire in 1862 as a result of a raid on the native village and the trading post by the Dakota Sioux.

In 1858 a competing fur company erected a trading post on the south side of Like-a-Fishhook Village which was first known as Fort Atkinson in honor of one of the partners of the new organization. The records pertaining to the new fort are much more abundant and detailed than in the case of Fort Berthold I. One of the junior partners wrote a series of long and descriptive letters concerning the post and even prepared a ground plan of it with an account of its appearance, the methods of construction, and the problems involved in its completion. Those letters together with other documents were preserved and are in the custody of the North Dakota State Historical Society. There are also numerous pictures including some photographs taken during the later days of the occupation of the fort. All that material was studied prior to the start of excavations. From the information thus available it was possible to identify most of the features within the stockade area and augment the written records with data obtained from the digging. Fort Atkinson was subsequently acquired by the owners of Fort Berthold I, and many of the activities of the old company had been transferred to it prior to the attack on and destruction of the original post in 1862. After its acquisition Fort Atkinson was renamed Fort Berthold and is commonly referred to as Fort Berthold II. From 1863 to 1867 it served as a military post, and following the removal of the troops downstream to the newly established Fort Stevenson it became the agency for the three tribes living at Like-a-Fishhook Village. In 1874 an extensive fire destroyed all the agency buildings, including the school, and three sides of the stockade of the fort. A new agency was constructed about $1\frac{1}{2}$ miles below the Indian village, and Fort Berthold II virtually passed out of existence. Approximately 75 percent of the remains of Fort Berthold II, including the stockade line and two bastions, was excavated. During the course of the work it was determined that the architectural style followed in the buildings differed from the corner-notched log structures with which most people are familiar and followed the French Colonial practice of having grooved corner posts into which horizontal square-hewn timbers were fitted. It is possible,

though not definitely established, that a similar type of construction was used in Fort Berthold I.

The digging at Fort Berthold II recovered a large number of objects illustrating household furnishings and utensils, tools and implements, and various subsistence items. In addition there were glass beads, steel arrowpoints, knife blades, iron axheads, and other similar items for the Indian trade. As suggested for Fort Berthold I, this material will be very useful in identifying comparable objects from Indian sites occurring elsewhere throughout the area. The entire site comprising Like-a-Fishhook Village and Forts Berthold I and II is now beneath the waters of the Garrison Reservoir.

Another trading post situated some distance upstream from the Fort Berthold location was also excavated. James Kipp, who had been involved in the start of a trading post at Like-a-Fishhook Village, had established and occupied a post during the winter of 1826-27 when the period of organized trade was just getting under way on the Upper Missouri. That post apparently was the immediate predecessor of Fort Union which became the great trade capital for that part of the Plains area. The short-lived Kipp Post had consisted of a stockade area enclosing several buildings. A party from the State Historical Society of North Dakota was able to trace the outlines of the stockade, locate the bastions, and determine the extent of the several log structures which had been used by the trader. Objects recovered there represent an earlier period than those from the Fort Berthold diggings and for that reason help to define more sharply the periods in which different types of trade objects were employed. The information from Kipp's Post will prove useful in augmenting and extending that from the historic sites farther downstream.

Just below the Oahe Dam, in the line of a large spillway, excavation of the remains of Fort Pierre II resulted in the tracing of the stockade outline and the uncovering of remnants of several structures. Fort Pierre II was built in 1858 as a replacement for Fort Pierre Chouteau, the American Fur Company trading post which was sold to the War Department in 1855 for use as a military post during the campaigns against hostile Dakota Indian groups. Because of the increasing Indian troubles and decreasing trade, Fort Pierre II was abandoned in 1863. The investigations at the site produced data on construction methods, specimens illustrative of many of the materials used in trade, and certain localized facts on the life and customs of a mid-19th-century frontier post.

In the Fort Randall area in South Dakota the locations of several trading posts and combined trading and military forts were investigated. One of the combined posts was Fort Hale, which probably was built in the late 1870's and occupied until 1884. Several miles

farther downstream was another site which had been both a military fort and a trading post. Technically the two were not a single site since their locations were separated by several hundred feet and they belonged to different periods. Historically they are known by the same name, Fort Lookout. The military post was built in 1856 and was abandoned in 1857 when the garrison moved farther downstream to the regimental headquarters at Fort Randall. The company quarters and officers' houses were dismantled, made into a raft, and floated down the river to Fort Randall. Because so little was left, the former location of the fort was not definitely known until a River Basin Surveys party found and established identification of the site in 1950. At the same time the party noted the remains of a trading post and did some digging in them. The Fort Lookout trading post had long been a puzzling problem because different explorers had reported it in widely separated locations. From a study of the records the National Park Service historians concluded that there must have been three posts bearing the name at different periods. Evidence from the excavated site indicates that it represented Fort Lookout II of the period circa 1833-1851. Maximilian in 1833 referred to it as "The French Post," and Chittenden in 1840 mentions that Capt. Joseph La Barge and Narcisse LeClerc had taken possession of the unoccupied buildings at Fort Lookout. There seems to be some question concerning the actual abandonment of the post, but evidence found during the digging indicated two occupations. It is known that an American Fur Company factor was there in 1846 and a large number of Sioux were camped nearby. It did not operate long thereafter because by 1851 it was reported to be in ruins.

In South Carolina, before the waters of the Clark Hill Reservoir covered the site, excavations in the ruins of Fort Charlotte showed that the main foundations and a considerable portion of the lower walls were still in place. The fort had been a square masonry structure measuring 170 feet on each side and had had bastions at the four corners. Structures within the fortification must have been of a more perishable nature because, with the exception of a small masonry building which must have been the powder magazine, no traces of barracks or offices were found. Numerous nails and bits of glass and china typical of that period were recovered, but there was little in the way of military objects. The digging showed that the fort had been built on the site of a former Indian camp or village. Artifacts from the aboriginal level suggested occupation by a group of Creeks who undoubtedly had moved on a number of years prior to the erection of the fort in 1766. It was placed there as a defense against the Creek and Cherokee Indians who from time to time raided the Scotch-Irish, French Huguenot, and German settlements of the Long Canes region

of upper Carolina. The fort was named for Charlotte Sophia, wife of George III, and for a short time was garrisoned by English troops. They were replaced in 1768 by a colonial detachment which was reinforced by the governor in 1774 when relations between the colonies and the mother country were becoming more troublesome. On June 26, 1775, in the first overt act of revolution in the southern colonies, a company of American Rangers seized the fort. It remained in American possession throughout the Revolution and unquestionably played an important part in bolstering the wavering loyalties of upper Carolina.

OTHER ACTIVITIES

In addition to the strictly archeological researches, investigations have extended into related fields. During the earlier years in the Missouri Basin the River Basin Surveys carried on paleontological and geological studies in a large number of reservoir areas. The University of Nebraska has cooperated in paleontological work in Nebraska, Kansas, South Dakota, and Wyoming. Geologists from the University of South Dakota have been checking on possible fossil quarries at the site of the Big Bend Dam on the Missouri River near Fort Thompson, S. Dak. Construction activities there have been exposing deposits representing several geologic periods. River Basin Surveys parties also made paleontological studies in several reservoir areas in Texas. In the Glen Canyon Reservoir basin on the Upper Colorado River full-scale investigations relating to the flora, fauna, geology, paleontology, and ecology, as well as archeology, were undertaken by the University of Utah and the Museum of Northern Arizona working in cooperation with the National Park Service. Publications on the results of those projects are now beginning to appear.

A chronology program for the Missouri Basin was started in January 1958 by members of the staff of the Missouri Basin Project of the River Basin Surveys in cooperation with representatives from 20 research institutions working in the Missouri Basin. Wood specimens have been collected to provide material for intensive research in dendrochronology so that master charts may be developed into which archeological wood samples may be fitted. Charcoal samples for radiocarbon dating have been selected on the basis of those which should provide dates to fill in the gaps in the chronological framework and aid in understanding cultural developments. There is at present a series of dates extending from A.D. 1800 back to 4674 B.C. After a considerable gap are the much earlier dates mentioned in connection with the early hunting peoples. They are approximately 6900 B.C., 7420 B.C., and 8533 B.C.

Pollen samples have been gathered preparatory to establishing a fossil pollen sequence for the area. The pollen is being studied by

Dr. Paul B. Sears of Yale University and Mrs. Catherine Clisby of Oberlin College. Other geologic-climatic studies may assist in assigning the older cultures to their proper periods. The results of this program thus far have helped to clarify a number of troublesome factors. The information has also made possible more efficient planning of the salvage operations.

Reprints of the various articles in this Report may be obtained, as long as the supply lasts, on request addressed to the Editorial and Publications Division, Smithsonian Institution, Washington 25, D.C.

New World Prehistory¹

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[With 7 plates]

THE prehistory of the New World is so multifaceted and complex that synthesis demands not only compression but rigorous selection. What strands of human activity can be followed most easily through the maze of the past? Which elements are the significant ones? These are always troublesome questions for the archeologist, and in the present case they are made more so by the tremendous range of space and time and by the quantity and quality of the data with which we are dealing. It is difficult to fix consistently upon criteria of comparison. The best we can do is to adhere to those universal themes of man's existence that leave their mark in or upon the earth: technology, environmental adaptation, subsistence, and settlement. These were not necessarily determinative of the form and elaboration of other aspects of man's life, but they provide a background and a base which is necessary to the understanding of societies and cultures in pre-Columbian America.

MAJOR PROBLEMS IN NEW WORLD ARCHEOLOGY

Before beginning this account of New World prehistory it will be well to review some of the major problems confronting the American archeologist, for it will be evident that the tentative conclusions which I have reached about these problems give the outline and structure to the present article. They are problems not unlike those of Old World prehistory [1, 2]² in that they are concerned with the great changes in man's adaptations to his natural and social environments.

Most briefly, and in approximate chronological order, these problems are as follows:

¹ Reprinted by permission from *Science*, vol. 131, No. 3393, Jan. 8, 1960.

² Numbers in brackets refer to references and notes at end of article.

1. Who were the earliest inhabitants of the New World? Were they food gatherers comparable in their simple subsistence technology to the peoples of the Old World lower and middle Paleolithic?

2. Where and at what time did the American big-game-hunting specialization of the Pleistocene arise? What were its relationships to the possible earlier food gatherers mentioned above? What were its relationships to the big-game-hunting tradition of the Old World? What happened to the pattern?

3. What were the origins and relationships of the specialized food-collecting subsistence patterns of the post-Pleistocene? Did Asiatic diffusions and migrations play a part in these developments, especially in the Arctic and Boreal zones?

4. Where and when were food plants first domesticated in the New World, and what was the effect of this on society and culture?

5. What is the history of pottery in the New World?

6. At what period and in what regions did sedentary village life based upon farming arise in the New World, and what was the history of the spread of this pattern in native America?

7. What was the nature of sedentary village life in the New World in those areas or regions where plant cultivation was poorly developed or lacking, and when did it occur? To what extent were such cultures and societies dependent upon the diffusion of ideas and elements from the village-farming pattern?

8. When and how did the native civilizations of Nuclear America come into being? What were their relationships within the Nuclear sphere? What were their relationships to non-Nuclear America?

In the statement of these problems and in the discussion that follows, certain terminology is used that needs explanation. This terminology also relates to the three diagrammatic charts (figs. 1-3) which summarize New World prehistory in broad eras or stages of subsistence technology (earlier chronological ranges) or settlement types (later chronological ranges). The term *food gathering* is applied to subsistence patterns where the gathering of wild plant foods or the hunting of animal life lacked regional specialization or technological diversification. This usage follows that of Braidwood in Old World archeology [3]. *Food collecting*, in contradistinction, implies both specialization and diversification in the taking and utilization of wild plant and animal foods. The other terms descriptive of types of subsistence and settlement—*incipient cultivation*, *village farming*, *towns and temples*, *cities*, and a few other special terms of this nature—are defined below.

The geographical arrangements and the designations of the charts deserve a word. Figure 1 is a cross section for an area that runs north and south through the western axis of the hemisphere. The

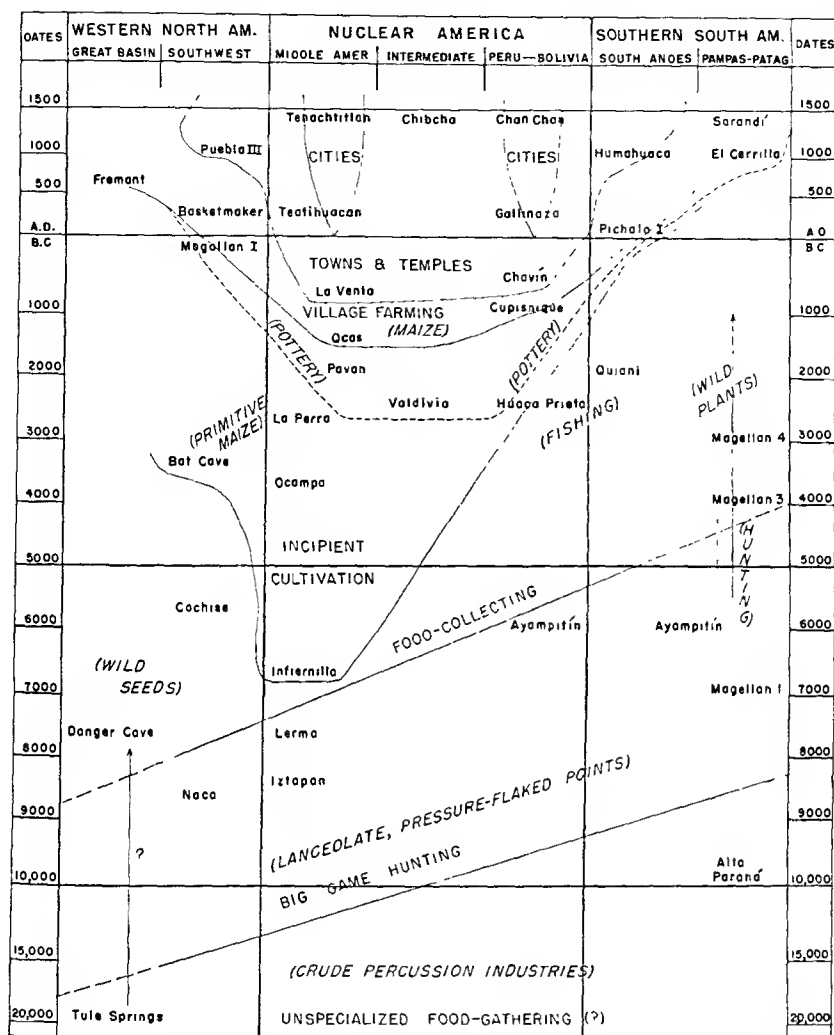


FIGURE 1.—Subsistence and settlement type levels in native America: cross section for western North America, Nuclear America, and southern South America. The first appearance of pottery is indicated by the dotted line.

name *Nuclear America* refers to the southern two-thirds of Mexico, all of Central America, and Andean and coastal Colombia, Ecuador, and Peru, with adjacent portions of Bolivia. This was the heart-land of native American agriculture and the seat of the two pre-Columbian centers of civilization, one in Middle America (Mexico-Guatemala) and the other in Peru-Bolivia [4]. There is a column for each of these two centers on the chart, and the column between, headed "Intermediate," refers to what I am calling the "Intermediate area" of southern Central America, Colombia, and Ecuador [5]. To

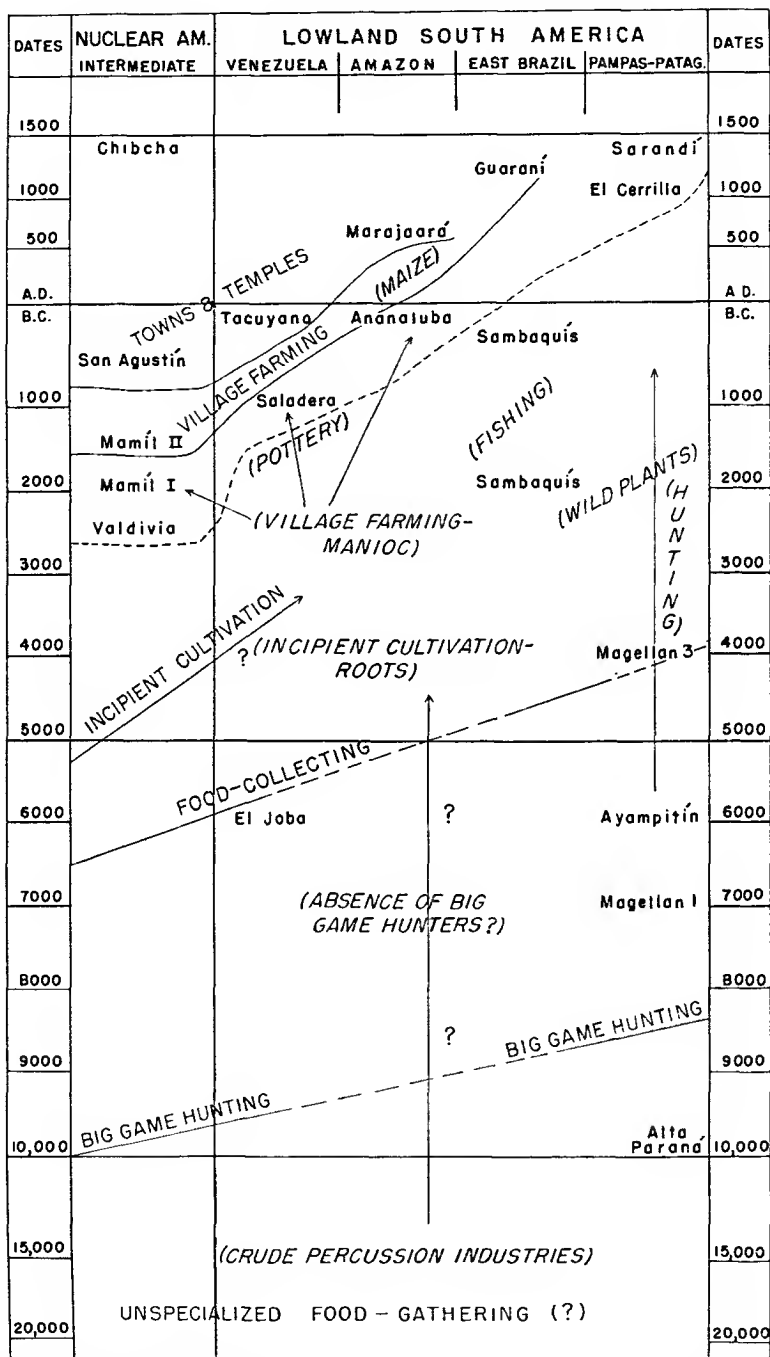


FIGURE 2.—Subsistence and settlement type levels in native America: cross section for Nuclear America and lowland South America. The first appearance of pottery is indicated by the dotted line.

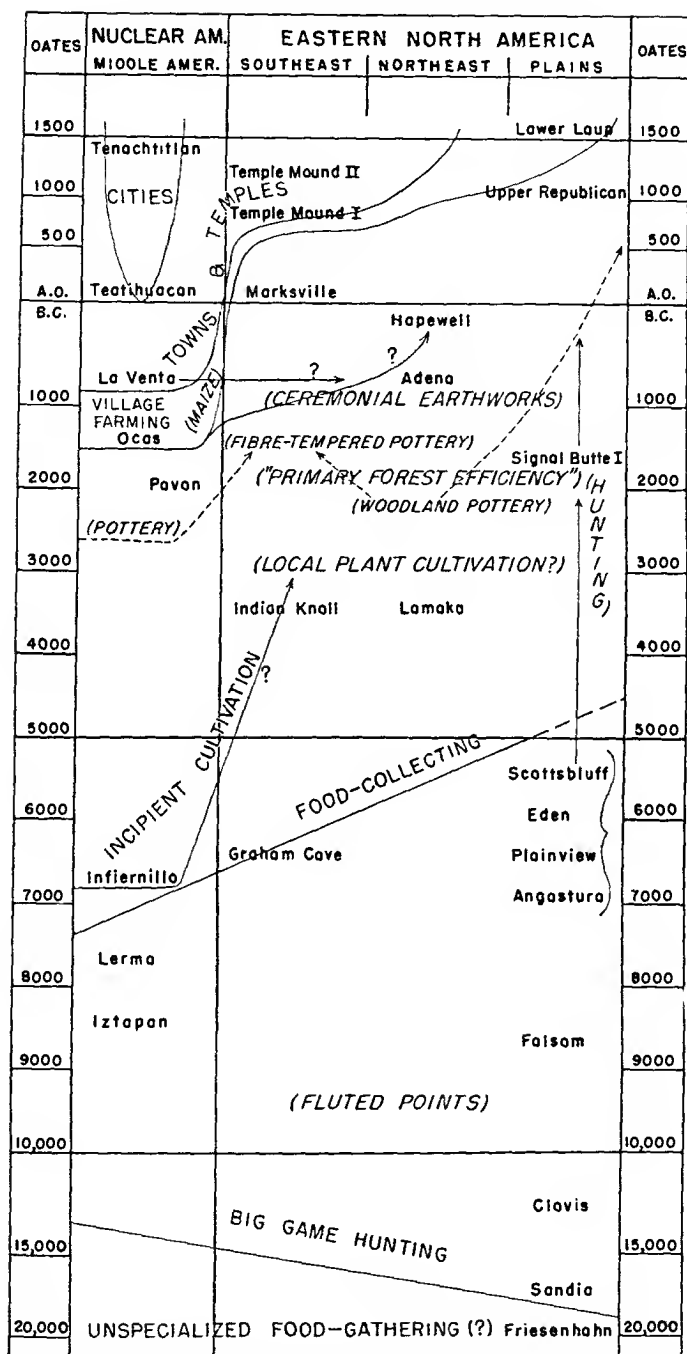


FIGURE 3.—Subsistence and settlement type levels in native America; cross section for Nuclear America and eastern North America. The first appearance of pottery is indicated by the dotted line.

the north of Nuclear America is western North America, divided into the Southwest culture area and the adjacent Great Basin area. Under "Southern South America" are columns headed "South Andes" and "Pampas-Patagonia." Figure 2 is a cross section for an area extending from the Intermediate area of Nuclear America eastward across Venezuela, then southeastward to the Amazon drainage basin and eastern Brazil, and finally south to the Pampas-Patagonia region. In figure 3 the "Middle America" column is repeated under "Nuclear America," and the cross section is extended to include the North American eastern woodlands and plains areas. The charts are highly schematic, and only a small number of archeological cultures, or phase names, have been entered in the columns for various areas. (These names appear in small letters.)

The point should be made that the diagonal and curving lines which mark off the major subsistence and settlement types on the charts are not impermeable ones [1, fig. 6]. Influences and traits crossed these lines, frequently moving outward from areas of cultural complexity and intensity into areas of simpler cultures. Such traits were often assimilated by the receiving groups without effecting basic changes in subsistence or settlement. In some instances suspected diffusions of this kind are indicated on the charts by means of arrows.

PLEISTOCENE FOOD GATHERING (?)

There are scattered finds in the Americas which suggest by their typology and chronological position that they may be the remains of early food-gathering societies [2, pp. 82-86; 6]. These artifacts include rough, percussion-chipped flint choppers, scrapers, and possibly knives or points, and occasional worked bone splinters. In some places, such as Tule Springs, Nev., or Friesenhahn Cave, Tex., these crude weapons and tools have been found associated with the bones of extinct Pleistocene mammals, so it is likely that some hunting, even of large game, was practiced [7, pp. 197, 218]. In general, however, the technological aspects of the implements show a lack of specialization toward hunting or toward any other particular means of obtaining food. In this the artifacts, and the inferences made from them, are analogous to those for the food-gathering cultures of the Old World lower and middle Paleolithic [8].

In age and geological placement, such putative early food gatherers in the Americas are not, however, comparable to those of Asia or any part of the Old World. At Tule Springs, a radiocarbon date (22,000 B.C.) indicates a context in the early substages of the Wisconsin glaciation, but in other localities, such as the lowest levels of Danger Cave, Utah [7, pp. 193-195; 9], or Fishbone Cave, Nev. [7, pp. 192-193; 10], the assemblage can be no older than the final Wisconsin

advance. Still other artifact assemblages that suggest an unspecialized food-gathering economy are not satisfactorily dated [11].

PLEISTOCENE BIG-GAME HUNTING

Sometime during the last Wisconsin interglacial era, or possibly even earlier, inhabitants of the North American continent entered upon a way of life that was based upon the pursuit and killing of the great ice-age mammals, such as the mammoth, the mastodon, the camel, and later the buffalo. The origins of this life pattern are unknown. There are no visible antecedents in the possible earlier food-gathering cultures of the Americas. There is, it is true, a general correspondence between this New World specialized hunting of Pleistocene fauna and what was going on in the Old World in the approximately coeval upper Paleolithic stage; yet even this possibility of a connection with the Old World does not provide a reasonable source for the big-game-hunting complexes of the New World, with their distinctive and highly specialized equipment. Apparently the forms which are most indicative of the American big-game-hunting technology are New World inventions.

The technical equipment associated with big-game hunters in the Americas includes lanceolate projectile points shaped by pressure-flaking. These are frequently distinguished by a channel fluting on both faces of the blade. A variety of skin-scraping tools accompanies the points as they are found in camp sites, "kills," and butchering stations [7, pp. 23-90]. The best documented of these discoveries come from the North American high plains in eastern New Mexico, Colorado, and Texas, and there are others from southern Arizona southward into Mexico. Some finds, such as those of the lower layer of Sandia Cave, N. Mex., may date back to before 15,000 B.C. [7, pp. 85-91; 12]. The Sandia complex is characterized by a lanceolate single-shouldered projectile point. Other discoveries, such as Clovis and Folsom, appear to be later, ranging perhaps, from 15,000 to 7000 B.C. The projectile points of both the Clovis (pl. 1) and Folsom complexes are of the fluted form [7, pp. 23-84]. There are also a variety of lanceolate, unfluted points that appear to mark a horizon subsequent to the Folsom. These include the Angostura, Scottsbluff, Plainview, and Eden types (see fig. 2) [7, pp. 107, 118, 138].

The spread of big-game hunting in the Americas took place during, and in the first or second millennium after, the final Wisconsin substage, the Mankato-Valders. The total span of time of this dissemination appears to have been from about 9000 to 5000 B.C. Finds of fluted projectile points throughout the eastern woodlands of North America indicate the former prevalence of the pattern there [13]. The Iztapan and Lerma remains in central and northeastern Mexico

[14], the El Jobo points of Venezuela [15], the Aympitín industry of the Andes and southern South America [16], and the Magellan I culture of the Straits [17] give the geographical range of the early big-game-hunting societies.

The fate of the big-game-hunting pattern is better known than its beginnings. After 7000 B.C. and the glacial retreats, there was a shrinkage of the total territory in which the big herbivores could be hunted. The intermontane basins and the range country of western North America became more arid, and a similar climatic shift took place in southern South America. After 5000 B.C., with a still greater increase in warmth and dryness, big-game hunting persisted in the central zones of the old continental grasslands, such as the North American plains and the Argentine pampas. In these areas a modified hunting pattern, based, respectively, on the buffalo and the guanaco, continued into later times. Elsewhere, populations of hunters probably were forced into new environmental situations and new subsistence habits.

LATER FOOD COLLECTING AND HUNTING

These new subsistence patterns can best be described as food collecting. They are differentiated from the possible earlier food-gathering pattern in that they show specialization in the exploitation of regional environments and much more effective technological equipment. Although the taking of game is a means of subsistence in some of these patterns, it is not the old big-game hunting of the Pleistocene. The food collectors, for the most part, developed cultures of greater material wealth, larger communities, and more stable settlements than their predecessors. There were exceptions to this, particularly in areas or regions of severe natural limitations and in the earlier periods of the food-collecting patterns; but on the average, and certainly at the optimum, these generalizations hold true [18].

Chronologically, most of the food-collecting patterns had their beginnings in the span of time between about 6000 and 2000 B.C. There were, however, exceptions to this, as in the North American Great Basin, where the specialized collecting of wild seeds was well established as early as 7000 or even 8000 B.C. [19]. As this is the same general area where clues to the most ancient food gatherers are found, it may be that there is a continuity in the Great Basin from the unspecialized gathering of the early Pleistocene to the later food collecting. According to this interpretation big-game hunting would be only partially represented or would be absent in an intervening sequence position [20]. This relationship is expressed in figure 1.

This possibility of continuities between the North American desert food collectors and earlier resident cultures and populations brings

attention to the larger question of the origins of the New World food-collecting patterns and peoples in general. There are three logical possibilities: (i) food-collecting societies and cultures were derivative, arising from the earlier food gatherers; (ii) members of such societies were the descendants of big-game hunters who were forced by the changing climatic conditions that followed the end of the Wisconsin glaciation to make readjustments; or (iii) they were more recent arrivals from the Old World by way of the Bering Strait. It seems quite likely that all three explanations may be useful, according to the particular geographical areas involved, and I have already mentioned the first two. The third explanation, that new arrivals from Asia played a part, is very probably correct insofar as the development of food-collecting cultures in northern North America is concerned. I have in mind particularly the northeastern woodlands, the northwest Pacific coast, and the subarctic and arctic. Elsewhere Asiatic influences were almost certainly of less direct account.

There are several major food-collecting patterns in the New World, and we can only skim over these very briefly. I have referred to what has been called a Desert pattern [21]. The long depositional histories at Danger Cave, Utah [9], Leonard Rock Shelter, Nevada [7, pp. 120-192; 22], and Fort Rock Cave, western Oregon [7, p. 184; 23] are representative, and the basketry and crude milling stones found at these sites testify to a seed-collecting and seed-grinding subsistence. A similar story is recorded in the Cochise culture of southern Arizona-New Mexico [24], and there are evidences of this Desert pattern in Mexico as well [25].

In the woodlands of eastern North America there is another collecting pattern that shows an adaptation to forest and riverine conditions in hunting, utilization of wild plants, fishing, and catching shellfish. Such sites as the Graham Cave, in Missouri [26], suggest that there was a transition in the eastern woodlands area, at about 7000 B.C., from big-game hunting to food collecting. In the ensuing millennia these Eastern Woodland collecting cultures, subsumed under the name *Archaic* in much of the literature [27], underwent progressive adaptations to regional conditions. By 3000 B.C. they were characterized not only by rough grinding stones and specialized projectile points but by numerous items of polished stone, such as vessels, celts, weights for throwing sticks, and various ornamental or ceremonial objects. The Indian Knoll, Kentucky [2, p. 116; 28], and Lamoka, New York [2, pp. 116-117; 29], phases are typical of their particular regions. Many of the Archaic sites are huge heaps of shells situated along rivers or on the Atlantic coast. Such locations were undoubtedly suitable for a semisedentary, or even sedentary, existence.

Along the Pacific coast of North America there was another food-collecting pattern which paralleled in many ways that of the Eastern Woodlands. Here, by 2000 B.C. if not earlier, semisedentary societies based upon fishing and acorn gathering were established all along the coast from southern Alaska to southern California [2, pp. 133-137]. In South America there were also ancient fishing societies along the coasts. The Quiani phase [30] of northern Chile displays this adjustment. On the Brazilian coast are the huge *sambaquis*, piles of shell refuse containing the skeletons and artifactual remains of food-collecting peoples who lived along these shores probably as much as two millennia before the beginning of the Christian Era [31]. Coastal shell-mound dwellers are also known from Venezuela at about this same period [32, 33].

I have mentioned that in both the North American and the South American plains there were retentions of big-game-hunting patterns into later times; even these cultures, however, show the result of contact with the neighboring food collectors in their possession of an increasing number of food-grinding implements. This is exemplified in the later North American Plains phases, such as the Signal Butte I [34], and by the later phases in the Strait of Magellan sequence and on the Argentine pampas [35].

INCIPIENT CULTIVATION

The change from food collecting to a subsistence based upon plant cultivation was one of the great turning points in human prehistory. This is true of the New World as well as the Old, and there are indications in both hemispheres that this switch-over was not a rapid one, but that it was effected only over a period of experimentation. It is this era of experimental or incipient cultivation in the New World that I now wish to examine [36].

In the Americas it would appear that there may be at least four distinct and semi-independent traditions of incipient farming. Two of these are Nuclear American. The northern one, the probable propagator of maize, was located in Middle America and in the adjacent deserts of northern Mexico and the southwestern United States; the southern one had its focus on the Peruvian coast. A third incipient-cultivation tradition centered somewhere in the tropical forests of the Amazon or Orinoco. Its existence is difficult to demonstrate archeologically, but such a tradition is needed to explain the domestication of manioc and other root crops. A fourth, and distinctly lesser, tradition rose in eastern North America in the Mississippi Valley system.

The earliest evidence for incipient cultivation in any of these traditions comes from northern Nuclear America. The region is the northeastern periphery of Middle America, in the semiarid hill country of

Tamaulipas. Here, preserved plant remains were taken from the refuse deposits of dry caves. In the Infiernillo phase, dating from 7000 to 5000 B.C., there are traces of domesticated squash (*Cucurbita pepo*) and of possible domesticates of peppers, gourds, and small beans. The cultural context is that of North American desert food collectors. There are, in addition to flint implements, net bags of yucca and maguey cords and woven baskets of a rod-foundation type. In the succeeding Ocampo phase, from about 5000 to 3000 B.C., beans were definitely domesticates. After this, between 3000 and 2000 B.C., a primitive small-eared maize came into the sequence in the La Perra and Flacco phases. R. S. MacNeish, who excavated and studied the Tamaulipas caves, has estimated the composition of food refuse of the La Perra phase to be as follows: 76 percent wild plants, 15 percent animals, and 9 percent cultigens. The La Perra and Flacco artifact inventories are not strikingly different from inventories of the earlier phases, although they demonstrate a somewhat greater variety of manufactures and an increased concern for seed foods. A few centuries later, at about 1500 B.C., an archeological complex which is representative of fully settled village farming appears in the region. Thus, the Tamaulipas sequence offers a more or less unbroken story of the very slow transition from food collecting supplemented with incipient cultivation to the patterns of established cultivation [37].

Early and primitive maize is also found to the north of Tamaulipas, actually outside of Nuclear America, in New Mexico. At Bat Cave, corncobs from refuse of a Cochise-affiliated culture date between 3500 and 2500 B.C. [38]. This is as early as the La Perra maize, or even earlier.

As yet, neither archeologists nor botanists have been able to determine the exact center of origin for domestication of maize in the New World, and it may be that this important event first took place in northern Middle America and in southwestern North America, where the intensive use of wild seeds in a food-collecting economy in a desert area provided a favorable setting. There remains, nevertheless, the very good possibility that a territory nearer the heart of Nuclear America and more centrally situated for the spread of maize in the hemisphere—an area such as southern Middle America—played this primary role in the cultivation of maize. The great difficulty is, of course, that the archeological record is so uneven, owing to the rarity of sites and environments where such things as plant remains are preserved in the earth. Such findings have not yet been reported in southern Middle America.³

³ They have been reported recently (1961) from southern Pueblo, Mexico, by R. S. MacNeish, who has found maize cobs, quite possibly of a wild variety, in cave refuse estimated to be as early as, or earlier than, La Perra phase. (Personal communication, R. S. MacNeish.)

Coastal Peru, at the southern end of Nuclear America, provides a rainless climate and splendid conditions for preservation of organic materials in open archeological sites, and it is in Peru that we have glimpsed what appears to be a second tradition of incipient plant cultivation in Nuclear America. At Huaca Prieta, in a great hill of marine shells, sea-urchin spines, ash, and other debris, cultivated squash, peppers, gourds, cotton, and a local bean (*Canavalia*) were found, along with an abundance of wild root plants and fruits. The people who raised and gathered these crops and seafoods lived at Huaca Prieta at least 2,000 years before the Christian Era. Whether there was, however indirectly, an exchange of domesticated plants between these early Peruvians and their contemporaries in Middle America is not certain. Such connections could have existed; or the beginnings of cultivation may have been truly independent of each other in these two areas of Nuclear America. Definite connections between early farmers of Middle America and of Peru appear, however, by 700 B.C. with the sudden presence of maize in Peru [39]. This maize was not, like that at Bat Cave or in the La Perra culture of Tamaulipas, of an extremely primitive kind. It was brought, or it spread, to Peru as a relatively well-developed plant, and it serves as a link to Middle America. We may conclude that Nuclear America possessed, from this time forward, a single major horticultural tradition, but by this time we have also passed beyond the chronological limits of cultivation incipience.

An ancient tradition of plant cultivation in the South American tropical forest [40] is based upon the presumption that a long period of experimentation was necessary for the domestication of such tropical root crops as bitter and sweet manioc (*Manihot utilissima*, *M. api*) and the yam (*Ipomoea batatas*). It seems reasonably certain that these domesticates date back to before 1000 B.C. in lowland Venezuela. This is inferred from the presence of pottery griddles, of the sort used for cooking manioc cakes in later times, in the Saladero phase at the Orinoco Delta by this date [32]. Also, the early archeological phase of Momíl I, in Caribbean Colombia, has the pottery manioc griddle [41]. The dating of Momíl I is debatable, but some of the ceramic traits suggest a date as early as 2000 B.C. Saladero and Momíl I are, however, outside the chronological and developmental range of incipient-cultivation patterns. They appear to be village sites based upon the cultivation of root crops, and as such they are comparable to, although historically separate from, village farming based on maize. I shall return to this point further along. For the present I bring these sites into the discussion because their existence implies centuries, or even millennia, of prior incipient root-crop cultivation in tropical northern South America.

A fourth tradition of incipient cultivation for the New World derives from the cultivation of local plants in the Mississippi Valley by as early as 1000 B.C. These plants include the sunflower (*Helianthus*), the goosefoot (*Chenopodium*), and the pumpkin (*Cucurbita pepo*) [42]. This domestication may have been in response to stimuli from Middle America, or it may have been an entirely independent development. This Eastern Woodland incipient-cultivation tradition was undoubtedly but a minor part of the food-collecting economy for a long time. Just how important it ever became, or how important that early diffusion of maize was to eastern United States cultures of the 1st millennium B.C., are crucial problems in the understanding of the area. I shall return to them later.

APPEARANCE OF POTTERY

Before taking up the rise of village farming in Nuclear America and its subsequent spread to other parts of the hemisphere, let us review the first appearances of pottery in the New World. Obviously, the line indicating the presence of pottery on the charts is not comparable to the lines indicating type of subsistence or settlement (figs. 1-3). American archeologists no longer consider pottery to be the inevitable concomitant of agricultural village life, as was the fashion some years ago. Still, ceramics, because of their very ubiquity and durability, are an important datum in many prehistoric sequences. Their presence, while not a necessary functional correlate of farming, at least implies a certain degree of cultural development and sedentary living.

At the present writing there seem to be two pottery traditions for native America. Curiously, the ages of these two pottery traditions—in the broadest sense of that term—may be about the same, 2500 B.C.

One of these pottery traditions, which we shall call the Nuclear American, is believed to be indigenous, but we can be no more specific about its geographic point of origin than to state that this is somewhere in the central latitudes of the New World. Actually, the earliest radiocarbon dates on the Nuclear American pottery tradition come from coastal Ecuador, in the Valdivia phase (pl. 2), and are from about 2500 to 2400 B.C. [43]. There are also early dates on pottery generally similar to that of Valdivia from Panama (about 2100 B.C.) [44, 45]. Thus, these earliest ceramic datings for Nuclear America are not from Middle America or Peru but from the Intermediate area, and this may be significant in following up origins, although the record is still too incomplete to say for sure. Both the Ecuadorean and the Panamanian early potteries are found in coastal shell-mound sites, and in connection with cultures about whose means

of subsistence it is not easy to draw inferences, except to say that full village farming was unlikely. Possibly marine subsistence was supplemented with incipient cultivation, although we have no proof of this. The Valdivia and the Panamanian (Monagrillo) pottery is reasonably well made and fired, the forms are rather simple, and the vessels are decorated with incisions, excisions, punctations, and very simple band painting. These early Ecuadorean and Panamanian styles may be part of a stratum of ancient Nuclear American pottery that underlies both Middle America and Peru. There are some indications that this may be the case, although the oldest pottery so far known in the Middle American and Peruvian areas dates from several centuries later [46]. In figure 1 the interpretation is offered that Nuclear American pottery is oldest in southern Middle America (for this there is as yet no evidence) and in the Intermediate area (for this there is evidence). Whatever the point of origin for pottery in Nuclear America, there is fairly general agreement that the ceramic ideas generated there carried to much of outlying North and South America.

The second major pottery tradition of the Americas is widely recognized by the term *Woodland*. Apparently not indigenous, but derived from northern Asia, it is best known from the eastern woodlands of New York and the Great Lakes region. So far, its presumed long trek from the Arctic down through Canada has not been traced [47]. Woodland pottery is generally of simpler design than the early Nuclear American wares. Of an elongated form, it is frequently finished only with cord-marked surfaces (pl. 3, fig. 1). As already noted, the oldest of this cord-marked pottery in the Americas may go back to 2500 B.C. [48]. Even if this early dating is not accepted, there is little doubt but that Woodland pottery was well established in eastern North America before 1000 B.C.

In spite of the fact that the Nuclear American and Woodland pottery traditions are so radically different, there are, interestingly, a few similarities. The most notable of these is the technique of rocker-stamping combined with incised zoning of plain surface areas, known in Nuclear America and in the eastern United States (pl. 3, fig. 2). The distinctive rocker-stamped treatment of pottery was accomplished by impressing the soft, unfired surface of a vessel with either a small straight-edged implement manipulated rocker-fashion or, possibly, with a fine-edged disk used like a roulette. The impressions left on the pottery may be either plain or dentate, and they always have a characteristic "zigzag" appearance. Rocker-stamping is found in the Valdivia phase in Ecuador, and it also occurs at about 1000 B.C. in parts of Middle America and in Peru [49]. In eastern North America it is not found on the earliest Woodland pottery but is found on

vessels which date from just a few centuries before the beginning of the Christian Era. Thus, the Nuclear American rather than the Woodland tradition has chronological priority in this trait in the New World [50]. Again, as with so many other problems that perplex Americanists we can only refer to this without coming to any conclusions as to the timing and direction of the flows of possible diffusions. Nuclear American and Woodland ceramics may in some way be related, but at the present state of knowledge they appear to have different origins and substantially separate histories (pl. 4).

VILLAGE FARMING IN NUCLEAR AMERICA

Braidwood and others have stressed the importance in the Old World of the threshold of the village-farming settled community [1, refs.; 51]. Although in its beginnings the agricultural village had a subsistence base that was no more adequate than, if as ample as, that of some of the food-collecting communities, this base offered the potential in certain Old World localities that led, eventually, to civilization. In the New World a similar development was repeated in Nuclear America.

In the New World the line between incipient cultivation and village farming has been drawn at that theoretical point where village life is, in effect, sustained primarily by cultivated food plants [52]. In archeology this distinction must be made by an appraisal of the size and stability of settlement as well as by direct or indirect clues as to the existence of agriculture. In Nuclear America the earliest time for which we can postulate the conditions of village farming is the 2d millennium B.C. For example, in Middle America in the Tamaulipas sequence the change-over from incipient cultivation to established cultivation takes place at about 1500 B.C. [53]. Elsewhere in Middle America the known sequences begin with the village-farming stage, as at Early Zacatenco [54] (Valley of Mexico), Las Charcas [55] (Guatemalan Highlands), Ocos [56] (Pacific coast of Guatemala), and Mamom [57] (Maya lowlands) [58]. In Peru the village-farming level is reasonably well defined with the appearance of maize in the Cupisnique phase and the shift of settlements back from the coast to the valley interiors. The date for this event is shortly after 1000 B.C. [59]; this suggests that the horizon for village farming may have sloped upward in time from Middle America to Peru (fig. 1). For the Intermediate area, where I have noted the earliest occurrence of pottery in Nuclear America, the threshold of village farming is difficult to spot. In Ecuador, the phases succeeding Valdivia have a different ecological setting, being inland in the river valleys rather than on the immediate shores [60]. Perhaps, as in Peru, this correlates with the primary economic importance of plant cultivation.

In Colombia, the Momil II phase, which is represented by a stable village-site area, is believed to have possessed maize [41].

The foregoing discussion carries the implication that village farming was a pattern diffused through Nuclear America from a single area or region. Essentially, this is the point of view expressed in this article. This is not to overlook the possibility that village agricultural stability may have arisen independently in more than one place in the New World. In fact, as I point out below, it apparently did just that in the tropical forests of South America. I am of the opinion, however, that in the Nuclear American zone the maize plant, genetically developed and economically successful, became the vital element in a village-farming way of life that subsequently spread as a complex. For the present, I would hazard the guess that this complex developed in southern Middle America and from there spread northward to Mexico and southward as far as Peru. This was, in a sense, its primary diffusion or spread. Afterward, there were secondary diffusions to other parts of the Americas.

THE VILLAGE IN NON-NUCLEAR AMERICA

These secondary disseminations of the Nuclear American pattern of village farming were responsible for the establishment of similar communities in areas such as southwestern North America, the southern Andes, lowland tropical South America, and the eastern woodlands of North America (see figs. 1-3). This process was relatively simple in southwestern North America and the southern Andes. The agricultural patterns were diffused to, or carried and superimposed upon, peoples with food-collecting economies of limited efficiency. In the Southwest, village farming and ceramics first appear at about the same time in such cultures as the Vahki, the Mogollon I, and the Basketmaker [2, pp. 151-155]. This was between 200 B.C. and A.D. 300. Moving from the south, the village-farming pattern pushed as far as the Fremont culture [61] of the northern periphery of the Southwest. In the southern Andes there is, as yet, no good hint of an early incipient-cultivation tradition, and, apparently, pottery and agriculture arrive at about the same time, integrated as a village-farming complex. This flow of migration or diffusion was from Peru-Bolivia southward. Pichalo I [30] of northern Chile marks such an introduction, as do the earliest of the Barreales phases [62] in northwest Argentina. The time is about the beginning of the Christian Era. Beyond the southern Andes the village-farming pattern did not diffuse onto the plains of the pampas or Patagonia.

The relationship of Nuclear American village farming to the tropical lowlands of South America was much more complex. There the maize-farming pattern was projected into an area in which village



Clovis-type projectile points and associated scrapers from the Lecler site, southern Arizona. These artifacts are comparable to those found at the nearby Naco site. They are representative implements of the North American Pleistocene big-game hunters. (Courtesy Arizona State Museum)



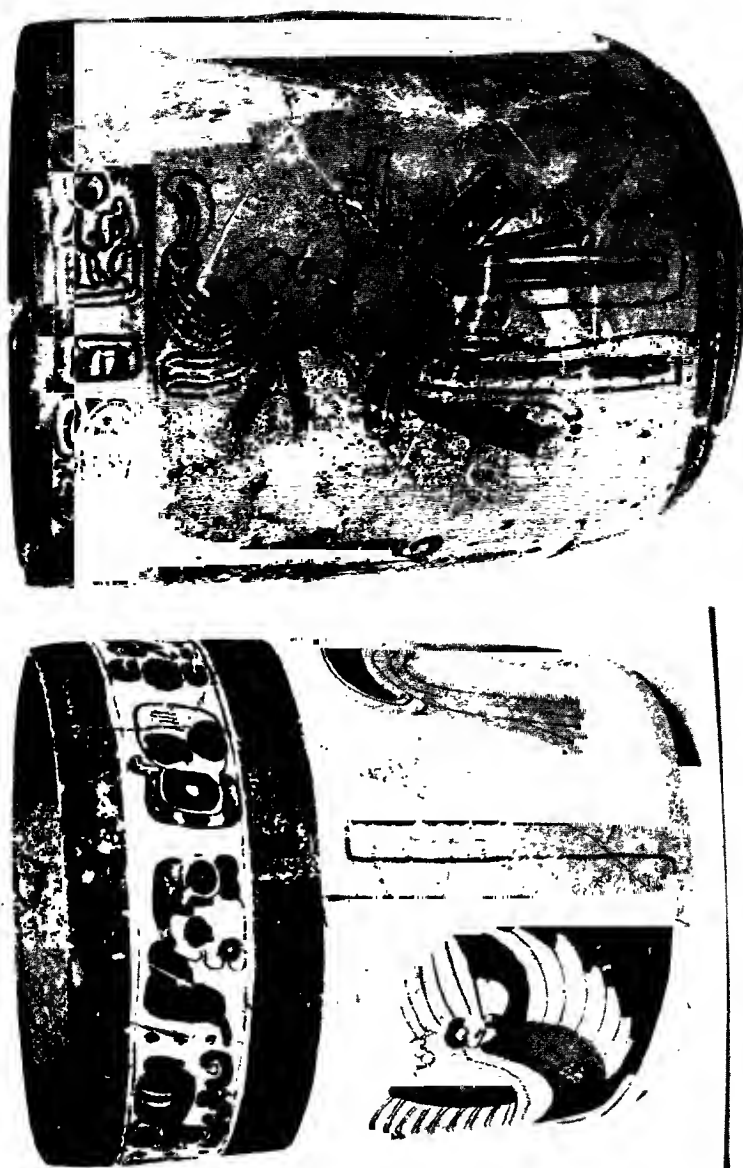
Valdivia style pottery (upper) and figurines (lower) from coastal Ecuador. This excised ware and the crudely modeled female figurines may be among the earliest ceramic manufactures of the New World. (Courtesy Emilio Estrada.)



1. Early Woodland pottery from New York State. Typical sherds of the Vinette I cord-marked ware, a ceramic that dates back 1000 B.C. or earlier. (Courtesy New York State Museum and Science Service.)



2. Fragment of a zoned rocker-stamped bowl from an early level (about 800 B.C.) of the Barton Ramie site, British Honduras (Mayan territory). (Courtesy Peabody Museum, Harvard University.)



Examples of fine Mayan Classic polychrome pottery, perhaps the peak of native New World ceramic art. Note the bands of hieroglyphs used as decorative borders. (After J. M. Longyear III.)



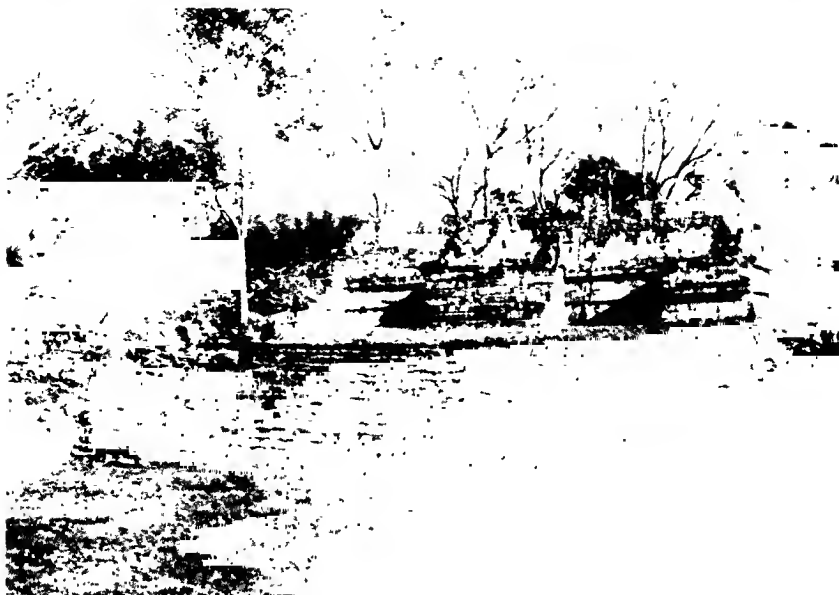
Beautifully carved smoking pipe showing the skill with which the Adena craftsman worked small objects of stone. (Courtesy Ohio State Museum.)



1. A Mayan temple of the Classic period, about A.D. 500 to 900. This is the famed "Temple of the Inscriptions" at the important ceremonial center of Palenque, Chiapas, Mexico.



2. A palace-type structure of the Mayan ceremonial center of Sayil, Yucatan, Mexico. This handsome building, now largely in ruins, was built of rubble faced with cut limestone blocks and mortar. It is estimated to have contained about 100 rooms. It was probably constructed, at least in its final phases, between A.D. 600 and 900.



1. A handsome masonry structure overlooking a plaza or courtyard. The building, resting upon an artificial terrace, is one of many at the Maya Classic period site of Copan in western Honduras. (Courtesy Carnegie Institution of Washington.)



2. A view of the great adobe wall bordering a side of one of the huge palace and living enclosures at the Peruvian north-east site of Chanchan. The ancient urban metropolis of Chanchan consists of several such enclosures. Chanchan was in its heyday in the 15th century, as the capital of the Chanu kingdom. It was taken over and destroyed by the Inca armies about A.D. 1470. (Courtesy Clifford Evans, Jr.)

life already existed. This is indicated in figure 2 by the entry "Village Farming—Manioc" in the columns headed "Venezuela" and "Amazon." Sedentary village life based upon root-crop farming is estimated to be as old as 2500 B.C. This is a guess, and, if it is correct, these villages are older than the Nuclear American village sustained by maize. Perhaps the estimated date is too early; however, at 2000 and 1000 B.C., respectively (see fig. 2), we have the villages of Momil I and Saladero, which, apparently, were supported by root-crop cultivation. It is of interest to note that Momil I, near the mouth of the Sinú River in Colombia, lies within the axis of Nuclear America; yet it differs from the succeeding Momil II phase at the same site in being oriented toward manioc rather than maize. This suggests that, in the Intermediate area at least, tropical-forest farming patterns may have preceded farming patterns for maize in Nuclear America.

Relationships between village farming in Nuclear America and in eastern North America are also complicated. It is unlikely that the local incipient-cultivation tradition in eastern North America ever matured into a subsistence pattern that could have supported fully sedentary village life. J. R. Caldwell [63] has argued that, in its place, a steadily increasing efficiency in forest collecting and hunting climaxed at about 2000 B.C. in a level of "Primary Forest Efficiency" (see fig. 3). Such a level, he concludes, offered the same opportunities for population stability and cultural creativity in the eastern woodlands as were offered by village farming. While agreeing with Caldwell that the efflorescence of Adena-Hopewell (about 800 B.C. to A.D. 200) [64] (pl. 5) is the brilliant end product of a mounting cultural intensity in eastern North America that originated in the food-collecting or Archaic societies, I am not yet convinced that plant cultivation did not play an important role in this terminal development. And by plant cultivation I am referring to maize, brought or diffused from Nuclear America. There is, as yet, no good direct evidence of maize associated with either the Adena [42] or the contemporary Poverty Point [65] culture. Maize is, however, found with Hopewellian cultures [63], although it has been assumed that it was of relatively little importance as subsistence at this time. I would argue that the riverine locations of Adena and Hopewell sites, together with the great size and plan of the ceremonial earthworks that mark many of them, make it difficult to infer an adequate subsistence if maize agriculture is ruled out.

To sum up briefly, the amazing cultural florescence of the Eastern Woodlands in the 1st millennium B.C. has not yet been satisfactorily explained. This florescence rests upon a chronologically deep series of Archaic food-collecting cultures which were at least semisedentary, and it contains elements, such as pottery, which are probably of

Asiatic derivation and which added to the richness of the Archaic continuum. But the sudden burst of social and cultural energy which marks the Adena culture cannot be interpreted easily without adding other factors to the equation, and perhaps these missing factors are maize agriculture and other stimuli from Middle America (see fig. 3).

Village life is, of course, present in native America in the non-Nuclear areas under conditions where plant cultivation may be ruled out entirely. Settled villages developed on the northwest coast of North America, with population supported by the intensive food-collecting economy of the coast and rivers. The same is also true for the coast and interior valleys of California. It is significant, however, that in neither of these areas did aboriginal cultivation ever make much headway, while in eastern North America it became a staple of life in the later pre-Columbian centuries.

TEMPLES, TOWNS, AND CITIES

In Nuclear America the town and eventually the city had beginnings in the settled farming village. A centralizing factor in this development was undoubtedly the temple. This earliest form of permanent structure usually had a flat-topped pyramidal mound of earth or rock as a base, and these mound bases of temples are found associated with some, but not all, of the village-farming cultures in Middle America [66]. At first, the importance of such a mound, and of the temple that stood on it, was probably limited to the immediate village. Sometimes these villages were small, concentrated clusters of dwellings; in other instances the settlement pattern was a dispersed one, with a number of small, hamletlike units scattered at varying distances from the temple center. Later on, the temple, or temple and palace structures, became the focal point of what might be called a town [67] (pl. 6 and pl. 7, fig. 1).

In Nuclear America the towns, like their antecedent villages, were either concentrated or dispersed. The former pattern developed in parts of Middle America, such as the Valley of Mexico or the Guatemalan Highlands, and in Peru; the latter was characteristic of the Veracruz-Tabasco lowlands or the Peten-Yucatan jungles of Middle America. In the towns the temple or ceremonial precinct was devoted to religious and governmental matters and to the housing of priests and of rulers and their retainers. The surrounding settlement zone, either scattered or concentrated, grew with increase in the numbers of farmers, artisans, or both. Trade was an important function of these towns.

In Nuclear America the town-and-temple community dates back to 800 B.C., a date that is applicable both to Middle America and to Peru. In the Intermediate area, between these two, town life was certainly

pre-Columbian, but its date of origin is difficult to determine because there is a lack of adequate archeological chronologies [68].

In lowland South America town-and-temple communities also antedate the Conquest, and it seems likely that these communities were, in part, the result of contact with and stimulus from the Nuclear American axis [69]. In the southern Andes the tightly planned clusters of rock and adobe buildings of the late archeological periods of northwestern Argentina reflect town and city life in Peru (pl. 7, fig. 2) and Bolivia [70]. Similarly, towns of the prehistoric southwestern United States relate to the Nuclear American zone. Development of these towns dates from sometime after A.D. 500, with an apogee in the Pueblo III and IV periods and in the Classic Hohokam phases [71].

On the other great periphery of Nuclear America, eastern North America, Middle American town life, with its temple mound-and-plaza complex, entered the Mississippi Valley sometime between A.D. 500 and 1000 and climaxed in the Mississippian or Temple Mound cultures shortly afterward [72]. Maize cultivation was an established part of this complex. Thus, in a sense, the thresholds of village farming and of the town-and-temple complex in the eastern woodlands, when these beginnings can be identified indisputably as of Nuclear American inspiration, are synchronous (fig. 3).

There remains, however, as in our consideration of the village-farming level, the puzzle of the Adena-Hopewell cultures. As we have already noted, the Adena-Hopewell ceremonial mounds and earthworks, built between 800 B.C. and A.D. 200, are of impressive size. Some of them are comparable in dimensions, and in the amount of coordinated manpower necessary to build them, with the contemporary mounds of Middle America. Although the mounds of Middle America were usually temple platforms while the Adena-Hopewell tumuli were mounds heaped up to cover tombs and sacred buildings, this dichotomy should not be overstressed. Some mounds of Middle America also were tombs, or combined tombs and temples [73]. In any event, it is safe to conclude that the Adena-Hopewell mounds were structures which memorialized social and religious traditions and served as community nuclei, as the ceremonial building did in Middle America. Was there a historical connection between Middle America and the Eastern Woodlands at this time, and was Adena-Hopewell ceremonial construction influenced by the emergence of the town-and-temple concept of Middle America? There is no satisfactory answer at present, but the possibilities cannot be dismissed (see fig. 3).

In Nuclear America the city developed from the town and temple, and there is no sharp division between the two. Size is, assuredly, one criterion but not the only one. These cities were the nerve centers of civilizations. They were distinguished by great public buildings

and the arts. Formal pantheons of deities were worshiped in the temples under the tutelage of organized priesthoods. Populations were divided into social classes. Trade, in both raw materials and luxury items, was carried on in these cities, and science and writing were under the patronage of the leaders [74]. Not all of these criteria are known or can be inferred for any one city in the New World, but many of them do properly pertain to Middle American and Peruvian sites from as early as the first centuries of the Christian Era.

Cities in the New World seem to have been of two types, and these types may have their antecedents in the earlier dispersed and concentrated towns. The dispersed city, with its ceremonial center and outlying hamlets, appears to have been orthogenetic in its traditions and to have drawn upon, and commanded, a relatively limited geographical territory. The great lowland Mayan centers of the Classic period, such as Tikal or Palenque, are representative [75]. The concentrated city adheres more to the concept of the city in the western European definition of the term. It was a truly urban agglomeration. Its traditions were heterogenetic, and its power extended over a relatively large territorial domain. The city was, in effect, the capital of an empire. Peruvian Chancha, Aztec Tenochtitlan, and probably, the more ancient Mexican city of Teotihuacan represent the type [76].

Although the cities and civilizations which developed in Middle America and Peru in the 1st millennium A.D. were unique and distinct entities in their own right, it is obvious that they also drew upon a common heritage of culture which had begun to be shared by all of Nuclear America at the level of village-farming life. This heritage was apparently built up over the centuries, through bonds of interchange and contact, direct and indirect. There are substantial archeological evidences in support of this supposition [77]. During the era of city life these relationships continued, so that a kind of cosmopolitanism, resulting from trade, was just beginning to appear in Nuclear America in the last few centuries before Columbus.

In the outlands beyond Nuclear America, trade and influences from the cities followed old routes of contact and penetrated and were assimilated in varying degrees. In the south Andes there was the very direct impact of the Inca state in the final hundred years before the Spanish conquest [70], and northward from Mexico, Toltec-derived influences reached the North American Southwest in relatively unadulterated form [78]. But, for the most part, the potentialities of the New World city for influencing and acculturating the "barbarian outlanders" were still unrealized when the Europeans entered the American continents.

COMMENTS

Conclusions are inappropriate to a synthesis which, by its nature, is an outline of opinion, however tentative. Retrospective comment seems more in order.

A few things stand out. The early inhabitants of the New World were not remarkably different in their mode of life from the food gatherers and hunters of the Old World; yet even on these early horizons, and despite the relatively limited cultural inventories available, dissimilarities of form are striking. The interrelationships of the two hemispheres during the Pleistocene are still very vague.

Plant cultivation in the New World—its incipient rise and its culmination as the most effective subsistence base of the Americas—is, of course, analogous to happenings in the Old World. The important American plants, however, are of local origin. In the Western Hemisphere the incipience of cultivation followed the end of the Pleistocene, and was not a great deal later, perhaps, than in the Old World Middle East. Yet the period of incipience was longer here; over 5,000 years elapsed before village life was sustained by crop cultivation. Is this because the first New World cultigens were inadequate as foodstuffs, and it was necessary to develop, first, the cereal maize before agriculture was made profitable?

Although there is a high correlation between village life and agricultural subsistence in the New World, there were New World societies and cultures which maintained villages without plant cultivation. In at least one instance, that of the ancient Adena-Hopewell development of eastern North America, community centers comparable to those of the contemporary farmers of Middle America may have been built and supported without a full-fledged farming subsistence.

I have slighted in this presentation the relationships between Asia and the Americas which were probably maintained from Pleistocene times down to the European conquest. This is particularly true of the cultures of the northern half of North America, where it is certain that there were contacts between the Old World and the arctic, subarctic, and northwest Pacific coasts. For Nuclear America nothing at all has been said of the possibility of trans-Pacific contacts between the Old World civilizations of China and Southeast Asia and those of Middle America and Peru. This undoubtedly reflects my own bias, but I remain willing to be convinced of such events and their importance to the history of culture in the New World.

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The Art of Seth Eastman¹

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[With 8 plates]

I. FORT CRAWFORD AND WEST POINT, 1829-40

IN the summer of 1848 a journalist visiting at Fort Snelling reported to his paper that Capt. Seth Eastman, the commandant, was "not only an accomplished soldier, but an artist of rare excellence, as his collection of original paintings and sketches abundantly testify, and, moreover, learned in Indian history and character * * * he had had rare opportunities, both in Florida and on the Upper Mississippi, for studying savage life, both in its warlike and peaceful aspects and with the true eye of artistical genius he has gloriously improved them." [1]²

If we cannot today go as far as did John Robb ("Solitaire") of the St. Louis Reveille in speaking of "rare excellence," we can agree that Eastman was a painter of talent and one who deserves a high place as a pictorial historian of the Indian. He may not have had the romantic glow of Alfred J. Miller or the showmanship of George Catlin, but he was an able painter and a careful ethnographer. He was in close contact with Indians for many years, particularly the Sioux and Chippeway near Fort Snelling, and his sketches testify to his sharp observation and his correctness of report. He learned to speak the Sioux language and was "so familiar with everything relating to the Dahcotah, or Sioux tribe, that he [could] * * * read the private history of a chief or brave by the ornaments which decorate his person," the admiring Robb declared. A fortunate combination of deep interest in the Indian and his ways, of devoted and continuous use of his opportunities, and of skill with pencil and brush enabled him to make a contribution of notable importance both historically and pictorially.

¹ Reprinted from a booklet to accompany a traveling exhibition of paintings and drawings circulated by the Smithsonian Traveling Exhibition Service, 1959-60.

² Numbers in brackets refer to list of references and notes at end of paper.

Eastman rose to the rank of brevet brigadier general before he retired, but his place in history is far more that of the artist than of the military man. Best known now for his rendition of Dakota Indian customs, he was a painter long before he undertook those subjects. Born in Brunswick, Maine, on January 24, 1808, the eldest son of Robert and Sarah Lee Eastman, he was appointed to the United States Military Academy on July 1, 1824, and was graduated and made a second lieutenant on July 1, 1829 [2]. During his years at the Academy the drawing master was Thomas Gimbrede, and it was perhaps under this French miniaturist and engraver that young Eastman had his early instruction in painting. Caustic William Dunlap thought the prints that Gimbrede published after his own drawings showed "his utter want of skill or knowledge in the art" and declared it "must have required uncommon talents . . . to teach that which he did not know" [3]. But Eastman somewhere learned both to draw and paint. A self-portrait which D. I. Bushnell, Jr., dated between 1829 and 1832 (on evidence of the uniform) is an early demonstration of skill in likeness [4].

Assigned to the First Infantry, in the fall of 1829 the young officer reported for duty with his regiment at Fort Crawford (Prairie du Chien), Wis. His earliest extant drawing is a pencil sketch inscribed "Miss. River. Fort Crawford, Prairie du Chien, 557 miles above St. Louis, Oct., 1829." It pictures the wooden fort constructed in 1816 and the straggling town just below it on the left bank of the Mississippi. The lithograph of "Prairie du Chien in 1830" in Henry Lewis's "Das Illustrierte Mississippithal" was based on this drawing. It was possibly on his way up the river to Fort Crawford that Eastman made the lost sketch of Cassville, Wis., that Lewis used for another of his illustrations, "Cassville in 1829."

From Fort Crawford Eastman was transferred early in the next year to the great northwestern outpost, Fort Snelling, at the junction of the St. Peters (now Minnesota) River with the Mississippi. There he remained until he was assigned to topographical duty on November 25, 1831. On January 9, 1833, he was relieved and ordered to the Military Academy to serve as assistant teacher of drawing. We can be sure that in these early years in the West he was sketching scenes and subjects, for all his life he had an urge to record what he saw, but nothing is actually known of his art activities save for the sketches mentioned.

Eastman returned to the Academy to find his old teacher Gimbrede dead. The post of teacher of drawing remained vacant until the arrival of Charles Robert Leslie from England late in the year. This eminent and popular artist, however, did not find the position as attractive as he had expected and was soon led to give up his place, sailing once more for England in April 1834.

Eastman, whose appointment dated from January 22, 1833, must have known Leslie and may have had some slight opportunity to study under him. Much more important to the young officer-artist, however, was Leslie's successor. Robert W. Weir on May 8, 1834, was named to the post which he was to fill for many years. Although only 5 years older than Eastman, he was already well known and highly thought of as a painter. Of this opportunity Eastman did make use; on one later occasion, at least, Weir was specifically mentioned as Eastman's teacher.

Eastman's duty during these 7 years on the faculty was military draftsmanship, and his serious concern with it is evident by his publication of a "Treatise on Topographical Drawing" (1837), which was used as a text at the Academy. The West Point Museum possesses a specimen of his technical work in a copy of a "Survey of Public Lands at West Point, 1723." It was probably the publication of his book and his growing repute as a painter that led to his election to the professorship of topographical drawing and painting in Jefferson College, Mississippi, in 1839—an invitation, however, which he declined.

Under Weir's direction Eastman must have gone seriously to work as a painter. A little oil on paper, "View of West Point," inscribed "Lieut Eastman Military Academy," must have been painted not later than 1835, for a lithograph by Pendleton, apparently made after it, was copyrighted in that year.

By 1836 Eastman had progressed sufficiently to have a canvas exhibited at the National Academy of Design in New York. The *New York Mirror* (June 25, 1836), admiring this picture, welcomed "this pupil of an accomplished master (Weir) to his stand among our landscape painters." The following year the National Academy of Design hung another of Eastman's paintings, and in 1838 eight of his pictures were accepted by them. Five of these were local subjects, the other three paintings being the earliest recorded of his western scenes. In praising one of these paintings ("Fort Snelling on the Mississippi near the Falls of St. Anthony") the *Mirror* (June 9, 1838) declared Eastman's works, as those of an amateur, "entitled to great praise. His distances and skies are generally extremely well-managed. His foregrounds, we think, want more warmth, and his figures should be more gracefully drawn."

After this considerable display of his talent, we are not surprised to find Eastman in 1838 elected an "honorary member amateur" of the National Academy of Design. This year he exhibited two more Hudson Valley scenes, both offered for sale. In the fall one painting was shown in New York at the Apollo Gallery (forerunner of the American Art Union).

Five more canvases made their first appearance in the 1840 spring show of the National Academy, but since Eastman was transferred

from West Point late in January of that year, they were almost certainly painted in 1839. One ("Sawing Wood") must have been a genre piece; the other four were landscapes. In October 1841, the Apollo Gallery had one of his paintings for sale ("View on the Hudson, near West Point"). Eastman's first period, devoted almost entirely to landscape, may be said to close at this point.

Possibly among the paintings just mentioned were two pictures found in St. Louis a decade later. An account contributed to the Missouri Republican (May 2, 1848) described them as—

full of the beauties of this accomplished artist; they form so many studies of foliage, and rock; so completely and laboriously, and with so much taste has nature been followed in her teachings. The views are of the falls opposite West Point, a bit of exquisite wood and water scenery scarcely to be equalled in the country, and known in times of yore, as the bath, and favorite resort, of Fanny Kemble * * *

The pictures are of that form of landscape, in which nearly all the canvas is taken up by the foreground, leaving only a glimpse of the sky, and giving but little chance for the careless and idle mode of painting which is so common when masses of foliage or rock are introduced. If not painted on the spot, (and we suppose they were, from their apparent accuracy,) they are at least the transcript of drawings so correct, that the botanic names of nearly every tree introduced, from the painting of the bark, and leaves, and branches, could be easily indicated; the rocks possess a form that indicates to you their exact geological relations * * * The figures of females bathing in one piece, and the solitary heron, a shy and distant bird, in the other, determine and mark the seclusion and privacy of the scene; and the cool tone through the pictures, with the disposition of shades and shadows, indicate the full noon of a sultry day overhead, but no sunbeams have reached the seclusion of this wooded recess * * *

The * * * two landscapes, painted some years since, are in the style of coloring common in England from the time of Gainsborough to that of Turner * * *

None of the paintings shown during these years at the National Academy of Design and the Apollo Gallery can be positively identified with extant work. However, we must certainly include among them the very pleasing oil "View of the Highlands, from West Point" (pl. 1), owned by Dr. and Mrs. Hermann Warner Williams, Jr. Several watercolors illustrate other views that took the painter's eye: "Constitution Island and Foundry from West Point, N.Y.," in the collection of the Corcoran Gallery of Art, and "View from Fort Clinton, West Point" belonging to Dr. and Mrs. Williams.

During his long tenure at the Academy Eastman was twice promoted—to lieutenant on November 14, 1836, and to captain on November 12, 1839. In 1835 he married 17-year-old Mary Henderson, daughter of Dr. Thomas Henderson, army surgeon from Virginia.

II. ON THE FRONTIER, 1840-50

For the next 10 years Eastman sketched and painted in many parts of the United States and became interested in studying and recording

the Indian way of life and the frontier landscape. Relieved at the Military Academy on January 22, 1840, he reported for duty with his regiment in the Florida (Seminole) War of 1840-1841. Three watercolors can be chosen to illustrate his southern tour. "View on the Suwannee River" is purely scenic. "Encampment of the 1st Infantry at Sarasota, Florida" pictures a row of tents under some magnificent live oaks. "Sam Jones' Village" preserves the remains of a Florida Indian village, that of the Seminole chief Arpeika, known also as Sam Jones.

An oil picturing "Osceola as Captive in an Open Tent, Guarded by a Sentry" poses a problem. The close attention to detail and the handling of the Indian costume certainly suggest Eastman as the author of this unsigned painting which until lately has been in the possession of his descendants. But the facts that Osceola died in Florida in January 1838, that Eastman did not arrive until 2 years later, that there is not the slightest resemblance between this realistic middle-aged Indian and Catlin's romantic young chief painted a few days before Osceola's death, and that Eastman commonly painted from life, all suggest that Eastman's subject must have been another warrior and that the picture was later mislabeled.

Eastman's next remove, after a 4-month sick leave resulting from the campaign in Florida, was to Fort Snelling in 1841. Although we have almost no details of his art activities during the next 5 years, apparently he painted many portraits, group pictures, and landscapes in oil and in watercolor and accumulated a large portfolio of pencil sketches. One of his few extant portraits, that of "Eta Keazah, Sisseton Sioux at Fort Snelling," assigned by D. I. Bushnell, Jr., to 1844, illustrates in the braiding of the hair and in the treatment of the headcovering the care for detail that was to characterize Eastman's painting of Indian subjects.

A glimpse of Eastman's relations as artist with the Indians was later recorded by Mrs. Eastman, who developed such a strong interest of her own in the Sioux that she wrote a book about them.

Our intercourse with the Sioux was greatly facilitated [she wrote], and our influence over them much increased, by the success attending my husband's efforts to paint their portraits. They thought it supernatural (*wahkun*) to be represented on canvas. Some were prejudiced against sitting, others esteemed it a great compliment to be asked, but all expected to be paid for it. And if anything were wanting to complete our opportunities for gaining all information that was of interest, we found it in the daguerreotype. Capt. E., knowing they were about to celebrate a feast he wished to paint in group, took his apparatus out, and, when they least expected it, transferred the group to his plate. The awe, consternation, astonishment and admiration, surpassed description. "Ho! Eastman is all *wahkun*!" [5]

In July 1846 the landscape painter Charles Lanman, visiting at Fort Snelling, was greatly impressed by the accomplishment of this "pictorial historian" of the Indian:

All his leisure time has been devoted to the study of Indian character, and the portraying upon canvas of their manners and customs, and the more important fragments of their history. The Sioux tribes have attracted the most of his attention, although he has not neglected the Chippeways, and he has done much to make us acquainted with the Seminoles of Florida, where he was once stationed for several years. Excepting a few which he has occasionally presented to his friends, all that he has ever painted are now in his possession, and it was my good fortune to spend many agreeable hours admiring their beauties. The collection numbers about four hundred pieces, comprising every variety of scenes, from the grand Medicine Dance to the singular and affecting Indian Grave. When the extent and character of this Indian Gallery are considered, it must be acknowledged the most valuable in the country, not even excepting that of George Catlin. But what adds greatly to the interest called forth by these pictures is the use to which they are to be applied. Instead of being used as a travelling exhibition to accumulate gold, this gallery is to be presented to a distinguished college, from which the artist will only demand the education of his children. There is something in this movement so foreign to the sordid passion of our age, and so characteristic of the true spirit of art, that the heart is thrilled with pleasure as we remember the American soldier-artist of the wilderness [6].

Though Eastman may not have had a "sordid" interest in gold, he certainly gave thought to earning money by his art, for he had five children to bring up. One scheme in his mind was a picture book of the Mississippi. Writing to Lanman from Fort Snelling, November 1, 1847, he thanked him for sending out the spring catalog of the exhibition at the National Academy of Design and lamented that he had never received the copy of Lanman's "A Summer in the Wilderness" that Charles Deas was to have carried out to him (for the good reason that Deas returned no more to the West). Eastman then continued: "I have recently written to Wiley and Putnam offering to sell them one hundred water coloured sketches on the Mississippi—for publication. They are views from the Falls to the mouth of the Ohio—I hope they will take them—Since writing to that firm, a gentleman has offered me a thousand dollars for the hundred sketches. He wishes to get them for another publication. I refused to sell them until I heard from Wiley and Putnam" [7]. Wiley and Putnam did not publish such a book. Whether Eastman sold the pictures or not, whether they were ever published without credit to him, what the specific subjects were, and whatever became of the originals—all remains tantalizingly dark, but it can be suspected, however, that some were subjects eventually used in illustrating Henry R. Schoolcraft's "Indian Tribes of the United States."

At this time, too, Eastman was exposed to the epidemic "panorama fever" that was afflicting many artists—the hope of making a for-



Face of the Highlands, from West Point. Collection of Hermann Warner Williams, Jr.

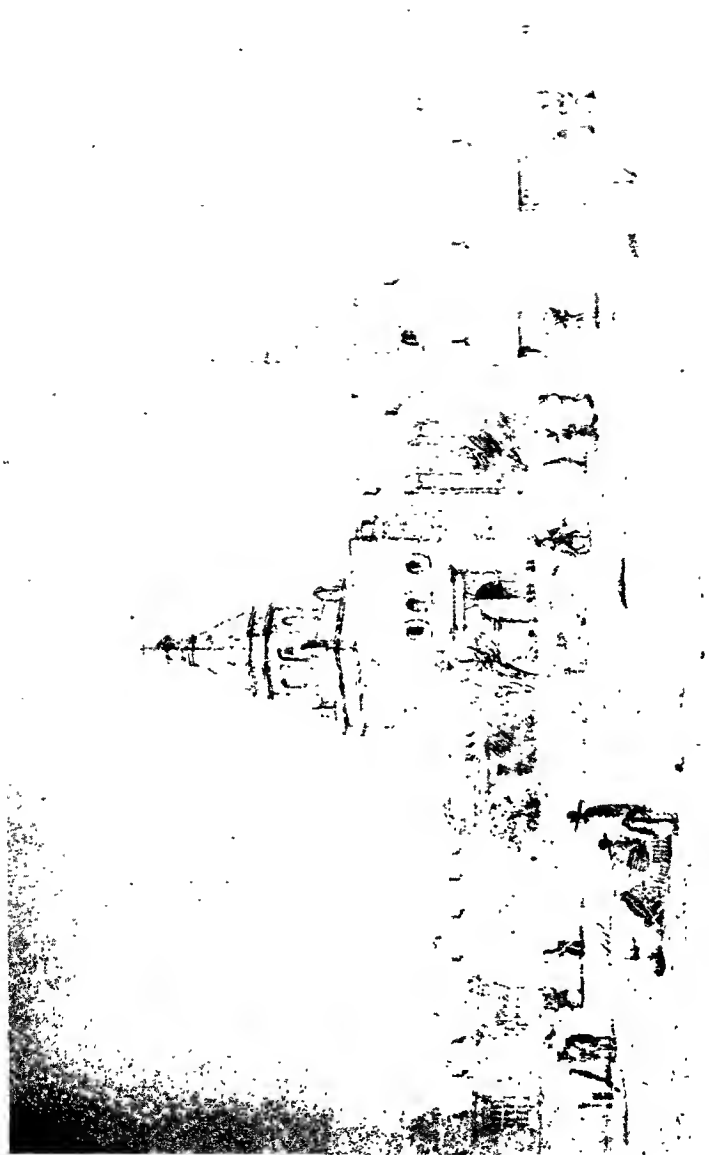


Plate at San Antonio, Texas, March 18, 1879. Peabody Museum, Harvard University.



Live Oaks, 2 miles from Fredrickburg, Texas. Encampment of Gaddo Indians, March 2, 1849. Peabody Museum, Harvard University.



Indians in Council. James Jerome Hill Reference Library, St. Paul, Minn.



Indian Doctor Concocting a Pot of Medicine. James Jerome Hill Reference Library, St. Paul, Minn.



PLATE 6

Mackinac. Aye Collection, Newberry Library, Chicago.



Sioux Indians Playing the Game of Plum Stones — Peabody Museum, Harvard University



Sioux Indians. Joslyn Art Museum, Omaha.

tune by the painting and exhibiting of a moving travelog 500 or 1,000 yards long. John Banvard, showing his so-called "3-mile" painting of the Mississippi River, was having tremendous success in the eastern cities. Two other panoramas of the Mississippi were in the making in 1847, and two more would be underway before Eastman was transferred from Fort Snelling in 1848 [8]. "There have been several artists here this season," the captain confided to Lanman in this same letter. "It has been proposed for me to join with one or two of them in painting a panorama of the Mississippi, from the Falls of St. Anthony to New Orleans—I have not yet decided—I dislike to leave my Indian pictures—My long residence among the Indians has given me a knowledge of their habits and character. For this reason these gentlemen wish me to unite with them."

Eastman probably referred either to John Rowson Smith or Henry Lewis, for both these painters visited Fort Snelling in 1847, and Lewis, in fact, was there at the moment the captain was writing. In the descriptive pamphlet issued for his panorama, Smith, on presenting the view of Fort Snelling, told his audience that "Captain Eastman, an eminent artist, whose Indian pictures are considered among the very best, is stationed at this post." Farther on, he acknowledged indebtedness to Eastman for his scene at Maiden's Leap, below Lake Pepin: "In the foreground is a delegation of Indians in canoes, meeting at a sand bar, to have a 'talk' about a treaty, taken from a splendid painting by Captain Eastman, for the Arts Union, New York" [9]. (Such a painting was *not* among those sold presently to the American Art Union; it may, however, have been one of the pictures disposed of late in 1848 to the Western Art Union at Cincinnati.) It has already been noted that Lewis based two scenes in his panorama on Eastman sketches and used them again for two of the lithographs in his "Das Illustrierte Mississippithal." As will be seen, Lewis and Eastman became good friends.

Fortunately, Eastman escaped the fever and stayed with the Indians, keeping steadily at work in the wilderness. When he wrote to Charles Lanman he mentioned two paintings, one just completed ("Indian Burial") and a companion piece that he was about to begin, showing "the scene that occurs immediately after the burial, representing the friends of the deceased tearing off their clothes and throwing them to the dead body, cutting off their hair, piercing their arms and legs, with their knives, etc.—It is one of the wildest scenes that occurs among the Indians.—" This painting has not been located, but the pencil sketch, "Indians Mourning," was undoubtedly a preliminary drawing of this subject. Of the first painting ("Indian Burial"), the St. Louis Republican expressed its hearty approval, both of picture and painter, saying—

His position and official station in the Indian country, and frequent contact with them, has enabled him to study minutely their character and peculiarities; and pursuing, for pleasure and amusement, the bent of his tastes, he has been enabled to transfer to canvas a more animated picture of real Indian life, than any we have ever seen before. Those who have attempted to sketch Indians in their homes, have been forced to take their impressions without the opportunity for minute study of cast or character. Generally, the Indian is averse to having his portrait, or any thing connected with him, painted. He believes it shortens his life. Capt. E. has had the opportunity to study his subject without these, or any other caprices, interfering with his purposes.

At least two more paintings were completed during the winter, about which "H.," writing in the *Missouri Republican* (May 2, 1848), described one as "the departure of Sioux Indians, on their way to confirm a treaty of peace with the Chippewas. We scarcely know which most to admire here—the truth in the delineation of the Indian figures, or the superb background landscape of the picture; take out the figures and it would still form a beautiful picture from the admirable delineation of the scenery. * * * One less observant with Indian character than Captain Eastman, could never have painted this picture."

It was this picture, contrasted with the two landscapes "found in St. Louis" about 1848 (discussed on p. 580) that showed the "onward progress of the artist." The earlier paintings, it will be recalled, were in "the style of coloring common in England from the time of Gainsborough to that of Turner." But this landscape with Indians, just finished, was "colored in the style of the great English master of landscape. We do not remember of having seen or known of a single painting by any American artist, except Eastman, that gives an idea of the warmth of the coloring of the school of Turner."

The other new work commented on by "H.," in the *Missouri Republican*, was of quite a different subject: "a home scene of Indian life." It was, said this writer,

quite unlike the vast mass of Indian pictures it has been our bad luck to see—for it is true. There is no attitudinizing—no position of figures in such a group that you can swear the artist's hands, and not their own free will, put them there. There is here the homely truth of an Indian cabin—the men lounging with their pipes in the distance, the women at work in the foreground: all the slight peculiarities, that would be unnoticed by an artist less conversant with the Indian life than Eastman, are brought forth, and the picture is full of objects suggestive of certain superstitions, habits, or ornaments, to one who knows any thing of Sioux life.

The year 1848, which saw the close of Eastman's service on the Upper Mississippi and of his contact with the northern Indians, was a busy and productive one for him. It cannot be determined how many of the pictures now to be reported were painted during his remaining months at Fort Snelling; perhaps some of them, presently to be sold to the American Art Union, had been the work of earlier

years at this post. Lanman in 1846 had reported that Eastman's collection then numbered "about four hundred pieces," a figure undoubtedly including watercolors and drawings as well as oils. Eastman himself in 1847 mentioned having 100 watercolors representing the Mississippi from Fort Snelling to the mouth of the Ohio and at a much later date declared that at the time he was assigned for duty within the Office of Indian Affairs he had had 67 paintings and sketches which he used in illustrating the Schoolcraft volumes [10]. Knowing Eastman, we can be sure that up to the last moment at the fort he was at his easel or had his sketchbook on his knee whenever opportunity allowed.

We can capture him on one occasion active both as soldier and as artist. In midsummer Henry Lewis was once more visiting Fort Snelling, this time on a sketching trip for his panorama. He arrived in the north in time to share in a bit of frontier excitement. Winnebagoes being removed upriver to a new reservation, at Sioux instigation balked when they reached Wahbasha's Prairie. The Indian agent in charge calling for reinforcements from the fort, Eastman went down with 25 soldiers and took over command. Lewis shared his tent. "At the upper end of the camp," the St. Louis artist wrote in his diary, "a sort of fort had been built with the waggon's running from the river bank and forming a square. Next to these were the tents of the dragoons, then the infantry then the friendly Sioux brought down from the St. Peters as allies of the whites in case of accident; and then the little band of regulars under Capⁿ Eastman." A "grand talk" was now the order of business, but the Winnebagoes "gave us to understand that they should move just when they got ready and such like." Eastman, hearing from one of the friendly Indians that the Winnebagoes might intend to surprise them, "order[ed] every man under arms and plac'd himself in order of battle, his line stretching from the river to the bluffs. Two six pounders were in the center supported by Cap Morgan's company of Dragoons. We had hardly got the line form'd when the Indians came dashing up at full speed—to the number of eight hundred all mounted and painted and dress'd in grand style they would dash up nea[r]ly to the guns of the men and not finding the line give way they would w[h]eel and ride back again yelling and shouting." For several days the situation was tense, but the captain, who was outnumbered at least four to one, by firmness and persuasiveness overcame the opposition without violence on either side. [11]. At some moment during these exciting days he made a vivid sketch of the scene described by Lewis, "Wahbasha's Prairie, Miss. River. Scene in July 1848." Needless to say, Lewis featured this bit of "Indian life" in his panorama and in "Das Illustirte Mississippithal," where a lithograph was devoted to the camp of the United States soldiers and several pages of text to Eastman's able handling of the difficult affair.

"Sioux Indians Breaking Up Camp," according to the Eastman notes, "explains itself. I wish to show that the squaws do all the labor & drudgery the men looking on doing nothing." This composition illustrates well Eastman's ability at once to report and to paint.

From the watercolor "Dog Dance of the Dakotas," used by the engraver of plate 22, volume 2 of "Indian Tribes," we can study Eastman's intention for a painting sold at this time to the American Art Union, though now lost.

Apparently when the Eastmans left Fort Snelling a "number of Indians" were shipped to Mrs. Eastman's brother-in-law, Lieutenant Craven, near Boundbrook, N.J. [12]. These the captain was anxious to dispose of, wrote Mrs. Eastman to Colonel Warner at the Art Union, "for he wanted them to be where they would be seen by artists, or persons of taste." Of this lot of 14 pictures which reached the Art Union on April 13, 1848, 5 were declined. In 1849 three pictures in this group were sold to the American Art Union. "Medicine Dance of the Dakotas" pictured "a large party of Indians beside their wigwams, engaged in the mystic ceremonies of the medicine dance" [13]. "Squaws Playing Ball on the Prairie" shows a large number of Indian women "engaged in this exercise, running swiftly in two opposing bands, while others in the foreground are looking on." The squaws, it seems, were permitted to indulge in the game after the men grew tired of playing.

The 6 remaining pictures in this lot of 14, among which was "Indians Playing Draughts," were bought by the American Art Union in 1850. And the following year they bought one more Eastman oil. It was probably not an Indian subject and might have been painted before the 1840's or even after his return to the East.

III. TEXAS AND "THE INDIAN TRIBES OF THE UNITED STATES," 1849-55

On March 3, 1847, Congress authorized the Bureau of Indian Affairs to collect and prepare for publication historical and statistical information concerning the history, condition, and prospects of the Indian tribes. Henry Rowe Schoolcraft was to gather the material and write the report. The post of illustrator remained for sometime unfilled. "Solitaire" Robb, in July 1848, was certain that Eastman was the man for the job. "The Government has recently commenced the collection of material for a correct work of Indian history, the habits and customs of the tribes, etc.," he wrote in the *St. Louis Reveille*. "We know not whether it is the intention of the projectors to illustrate this work; but we cannot well understand how they could give a proper history of this character without illustrations; and if such is the purpose, Capt. Eastman possesses more ability for such a task than any man in this country. It would be hard to find a man

possessed of the same artistical ability, who combined with it a thorough knowledge of Indian character. Illustrate such a work by all means, set Capt. E. to work upon it, and our country will possess a history of its original inhabitants which will reflect credit upon the administration under whose direction it is produced." Eastman, naturally, was eager for the appointment, but it was slow in coming.

Late in the summer of 1848 Eastman received orders transferring him to Texas and near the close of September he started down the Mississippi. With his pencil in his hand at every moment military duties would permit, he recorded many scenes on the river. Among the excellently detailed (and dated) drawings made near Fort Snelling before he left is "Miss. River. Mendota from Fort Snelling, 869 miles from St. Louis, Sept. 1848." Dropping down the river with the artist we may note as representative of his interests and his skill such views as the beginning of "Miss. River. Prairie La Cross, 90 miles above Prairie du Chien, 647 miles above St. Louis, Oct. 1848" and "The Mountain that Soaks in the Water, Miss. River. 690 miles above St. Louis" (Mount Trempeleau). A wealth of other sketches in the Peabody Museum and the Minneapolis Public Library, registering the Upper Mississippi scene, form a pictorial report of great value.

Early in October Eastman passed through St. Louis [14] (his friend Henry Lewis was then in Cincinnati at work painting his panorama). By December the captain was out beyond San Antonio, deep in the heart of Texas. His first impressions of the Southwest he put into a letter to his friend Henry S. Sibley [15]:

Camp of Co. D. 1st Inf. near Fredericksburg, Texas
Dec. 9th 1848

Dear Sibley,

I have at last arrived at my journey end. and landed I know not where—but in a very fine country, full of game and Indians. We have been travelling ever since leaving Fort Snelling till yesterday, when we arrived at a halt, for a few months, at least,—When we arrived at New Orleans, we expected to go on directly to the Rio Grande—but the Texians kicked up an Indian excitement, which caused Gen^l Twiggs to order my company up into these regions, and Burbank's and Scott's about 70 miles further west—This place is a dutch settlement, about eighteen months old, about 80 miles north of San Antonio—and pretty well into the Cumanche country. There [*sic*] trading post is here—Besides the Cumanches, we have the Delawares, Shawnees, Wakoos, and Lissan [?] Indians—Santa Anna, the Cumanche chief is to visit me in a few days, when I am to hold my first talk with his honor—The country is full of games—small games—such as Buffalo, Bear, Deer, Catamounts, Tigers, Turkeys in droves, a few quail and ducks—It would surprise you to see the herd of deer that we saw on our route—They are very tame and easily killed—Buffalo meat sells in town at 3 cents per pound a deer one dollars—Salt 8 cents per pound Flour \$20 per barrel. Vinegar one dollar per gallon etc. etc.

I wish you were here to go hunting with me, it is rather dangerous, but very exciting.

I presume my wife has written to you before this concerning the stock etc. I hope you have been able to do something for me in regard to my painting those Indian pictures—

If perfectly convenient I wish you would forward me a copy of the Documents accompanying the President's Message and such other documents as you may think would interest me.

As I am 70 or 80 miles from any mail route you will have to direct them to San Antonio, Texas, from whence I will obtain them by express—

Six companies of the 3^d are stationed at San Antonio—

Please drop me a line and let me know what is going on in the U.S. and especially in Congress—

Remember me to your wife and sisters at St. Peters—

Yours truly

S. Eastman

Capt. U.S.A.

Hon H. S. Sibley

Delegate from Minnesota Ter.

Apparently there was little action at this outpost of the Texan frontier, and Eastman had time for many pictures. He had made "a great many Sketches," Mrs. Eastman wrote to Sibley from Concord, N.H., January 4, 1849, "every thing is new to him." Passing through San Antonio, Eastman found it "a wretched place—full of desperate characters," as he wrote to his wife [16], but he sketched busily away, making views of the entrance to the city from the south, of the church of the Alamo, of Conception Mission, and of many other historic and, to him, unusual spots. A view of the ruins of the "Alamo at San Antonio, Dec. 1848" in watercolor and a pencil sketch of the "Plaza at San Antonio, Texas" dated March 18, 1849 (pl. 2) are representative of these city views. At the army camp at Fredericksburg he did not spend all his time hunting "games" or talking with Indian chiefs. Among the works done there is an excellent pencil sketch of "Live Oaks 2 miles from Fredericksburg, Texas, Encampment of Caddo Indians, March 2, 1849" (pl. 3). Such trees were also the subject of an attractive oil in the Bushnell Collection at the Peabody Museum, "Live Oaks with Two Small Figures."

On August 28, 1848, before he left Fort Snelling Eastman had sought to be ordered "to the duty of painting, if the work being compiled on the N. American Indians is to be illustrated with engravings etc.," but the War Office replied on November 14 that his services were required with his company and that he was not recommended for duty with the Indian Office [17]. Eastman's next step was to seek a furlough—except for the 4 months of sick leave in 1841, his first in more than 20 years' service.

In the meantime Mrs. Eastman had taken the five children east placed some of them in schools, and settled down with two at her

father-in-law's house in Concord, N.H. She handled the sale of the pictures to the art unions. She went after their old friend Henry Sibley of Mendota, now Minnesota territorial delegate to Congress, to use his influence to get the painter home. "Capt. E. in his letter tells me to remind you of your promise to endeavour to get him ordered to Washington and if this is refused—perhaps you could succeed in getting his furlough," Mrs. Eastman wrote to Sibley on December 20, 1848. "Will you be kind enough to write me if you think there is any prospect of Capt E's succeeding in being ordered to Washington to paint the pictures for government, or as illustrator to the work on Indians," she requested in another letter. Presently a 5 months' leave was granted him but his return was delayed first by the absence of another officer and then by news of cholera en route [18].

Once back in Washington, Eastman was able to win the transfer he so much desired and for which he was so ably qualified. War Department Special Orders No. 13, dated Washington, February 27, 1850, directed him at the expiration of his present leave (March 1, 1850) to report for duty at the Office of the Commissioner of Indian Affairs "for the purpose of completing the work on which he has of late been engaged, relating to the Indians" [19].

The phrasing of his orders suggests that Eastman had been devoting at least part of his leave time to working with Schoolcraft. That this must have been so seems to have been confirmed by the many illustrations Eastman contributed to Schoolcraft's first report, submitted to the Commissioner of Indian Affairs on July 22, 1850. Seventy-six pages of carefully detailed and beautifully drawn maps and sketches of Indian weapons, musical instruments, tools, costumes, artifacts, pictographs, of scenic views and of tribal customs are not produced overnight. Eastman was continued on this duty until War Department Special Orders No. 85, Washington, May 10, 1855, relieved him from the duty to which he had been assigned five years before and ordered him to rejoin his company [20]. In all, he prepared for the first five volumes of "The Indian Tribes of the United States" about 275 pages of illustrations. The engravings credited to Eastman in the sixth volume were restrikes from plates previously used.

Of particular interest pictorially are the 66 plates after Eastman's own sketches and watercolors (17 others were by Eastman after original sketches by Schoolcraft, R. H. Kern, E. M. Kern, Lewis Brantz, Lt. Col. J. H. Eaton, Maj. E. Backus, and George Gibbs). Some of these engravings were after slightly changed versions of earlier paintings, but for many of the others we know of no oil original, though some may once have existed. But for all the engravings Eastman apparently painted watercolors.

Many of these little pictures (most of them about 9½ by 6½ inches) prepared for the Schoolcraft volumes from the sketches in Eastman's portfolio are happily extant. "The Falls of St. Anthony" from the Minneapolis Public Library is much superior to the story-illustrating version published in *The Iris* for 1852, the original of which is among the watercolors in the James Jerome Hill Reference Library in St. Paul. "Old Fort Mackinac," from the Minnesota Historical Society, is signed and dated 1851. "Hunting Buffalo in Winter," "Herd of Buffalo," "Nadowaqua," and "Mackinac" are among the Eastmans in the Ayer Collection at the Newberry Library. "Winnebago Wigwams," dated 1850, is in the collection of the Peabody Museum.

The largest collection of these watercolors is that of the Hill Reference Library [21]. Two of these—"Itaska Lake" and "Chicago in 1820"—were painted after sketches by Schoolcraft. One Indian genre piece pictured "Emigrants Attacked by Comanches." Another showed "Pawnees Torturing a Female Captive." Seventeen more watercolors recorded many details of life among the northern Indians whom the artist knew so well. Here we can see a permanent "Dakota Village" with figures in natural groups, and a temporary encampment with tepees placed by the riverside, "Dakota Encampment." We can observe them dancing the Dog Dance, the Beggars Dance, and sitting in council (pl. 4). A warrior shouts "The Death Whoop" over a freshly scalped enemy, or we see an "Indian Doctor Concocting a Pot of Medicine" (pl. 5), or "Indian Medas [priests or magicians, not medics] Secretly Showing the Contents of Their Medicine Sacks to Each Other." Many of the pictures are more domestic: one illustrates the manner in which a Dakota sat, another shows a nude woman ceremonially "Protecting the Cornfields from Vermin." Indians are seen "Spearing Muskrats in Winter," gathering wild rice, and working at an "Indian Sugar Camp."

In some instances we are able to compare the watercolor with the on-the-spot pencil sketch that preceded it. The pencil sketch of "Mackinac," with the fort on the bluff and the town sprawling out on the lakeshore, has been faithfully reproduced in the watercolor by the same title (pl. 6), but the topographical effect has been relieved by the addition of a number of small figures appropriately grouped in the foreground.

One painting, now lost, represented by a plate in "The Indian Tribes of the United States," is a landscape worth rediscovery: the "Valley of the St. Peters." Among many scenes of Indian life, engravings preserve in some degree Eastman's representation of the Dakotas at "Ball Play on the Ice" on the St. Peters River (published first as an etching by the American Art Union in 1850),

"Transporting the Wounded," dancing the sun dance and the dance of the giant Indian, and "striking the post" as volunteers for a war party boast of their deeds. The women are shown "feeding the dead," procuring fuel, and are portrayed in an excellent pencil sketch, "Sioux Indians Playing the Game of Plum Stones" (pl. 7). A buffalo hunter is dismounted, a buffalo is being skinned, a skin is being prepared by the women. An Indian seer attempts to destroy a girl by means of a pencil of light. Winnebagoes dance the medicine dance in the lodge (in contrast to that of the Sioux danced in the open, the subject of an earlier oil).

Eastman's production during this third period of his art career was not limited to the work for the Schoolcraft volumes. Mrs. Eastman published a series of volumes of Indian lore, all illustrated by her husband. "Dahcotah; or, Life and Legends of the Sioux around Fort Snelling" (1849) had been completed before they left the northern post. For it Captain Eastman supplied four illustrations, all lithographed by Ackerman. To "The Iris, An Illuminated Souvenir for 1852" Mrs. Eastman contributed a number of stories and poems about the Indians; her husband furnished eight pictures which were atrociously chromolithographed. Happily, watercolors of all these subjects are in the collection of the James Jerome Hill Reference Library, among which are "The Laughing Waters, Three Miles below the Falls of St. Anthony," "Indians Courting," "Wenona's Leap," "Marriage Custom of the Indians," "The Falls of St. Anthony," and "Mission Chapel of San Jose" [22]. Two more of Mrs. Eastman's books illustrated by the works of her husband, "The American Aboriginal Portfolio" (1853) and "Chicora and other Regions of the Conquerors and Conquered" (1854), contain no new work by the painter; the 21 and 26 pictures, respectively, in these volumes were from the plates of "The Indian Tribes of the United States." (Lippincott, Grambo & Co. of Philadelphia was the publisher of all three works.)

In addition to these watercolors one of Eastman's finest extant oils, "Sioux Indians" (pl. 8), was painted in 1850 while in Washington from sketches made while in Minnesota. This painting portrayed a group of Indians by a riverside.

That Eastman's interest was not confined to the past and to the Indian country is made clear by a sketchbook in the M. and M. Karolik Collection at the Boston Museum of Fine Arts (now not available for publication), which contains among others about 25 sketches of Washington and its vicinity drawn soon after his arrival in 1850. The Bushnell Collection at the Peabody Museum also has many drawings and watercolors of Washington and Virginia about this time.

IV. LATER WORKS, 1855-75

At the close of his duty with the Bureau of Indian Affairs Eastman was ordered to the Texas frontier. On October 31, 1856, he was promoted to major (Fifth Infantry), and in 1857-58 he was again in Washington, this time on special duty in the Quartermaster General's Office. Later in this year he was once more on frontier duty conducting recruits to Utah. From 1859 to 1861 he was in Washington. He served in various capacities during the early years of the Civil War, was promoted to Lieutenant Colonel, First Infantry, on September 9, 1861, and on December 3, 1863, was retired from active service "for disability, resulting from long and faithful service, and for disease and exposure in the line of duty." He remained in command at successive posts, however, until September 1867. He was brevetted colonel and brigadier general on August 9, 1866, for services during the Civil War.

It cannot be imagined that Eastman ceased during these years to draw and to paint, but no work has been located. Only one picture is on record ("Buttermilk Valley, New Jersey"), which was sold to the Cosmopolitan Art Association in 1857.

After his retirement Eastman did take up the brush again and painted 26 canvases for the Capitol in Washington. In March 1867 it was proposed in the House of Representatives that he be employed to execute "paintings from his own designs for the decorations of the rooms of the Committee on Indian Affairs and on Military Affairs of the Senate and House of Representatives, and other parts of the Capitol." War Department Special Orders No. 427, on August 28, 1867, accordingly placed him on the active list and assigned him to duty under the Secretary of the Interior.

In the next 2 years he produced nine paintings of Indian life based on his Minnesota sketches, which today hang in the room of the Committee on Insular Affairs in the House Office Building in Washington.

His last commission (June 1870) was to paint for the House Committee on Military Affairs 17 pictures of forts, which hang in the west corridor of the main floor of the central portion of the Capitol. With the exception of Fort Sumter these were contemporary views intended as "illustrations of the conditions of the fortifications existing at that period" [23].

General Eastman died at Washington on August 31, 1875.

V. THE ACHIEVEMENT OF EASTMAN

"Since we have known something of Eastman's pictures, and of Indians," asserted the St. Louis Missouri Republican on May 2, 1848, "we have ranked him as out of sight the best painter of Indian life the country has produced."

There is truth in this contemporary judgment. Charles Deas had been a great favorite in St. Louis during the 1840's and with the Republican, too, but he loved to paint drama and violence—a man on horseback caught with a child in a prairie on fire, a mountain man and an Indian engaged in a struggle that will clearly be deadly for both, a trapper on horseback poised on the very edge of a cliff. George Catlin, through his exhibitions the most widely known painter of Indian subjects, was not a general favorite in the West, though he had supporters there. Dominated by his plan for an exhibition gallery, a traveling show, he worked quickly and unevenly to accumulate an array of canvases to take on the road. In his work there is "an effort at effect," as the Republican put it, an awareness of show potentialities, an eye to audience response. His portraiture and his studies of Indian customs are often well done, informative, and impressive; his contribution pictorially and ethnographically is important. But the Indian to him was a figure of romance and a source of art-capital. He had not the leisure or the inclination to be quietly objective as Eastman was. Nor could he paint so well.

In making any comparison today two other painters of that era must be considered. Alfred J. Miller, in pursuit of wild sports in the Far West in 1837, produced 200 superb watercolors shining with a glamor of romance never achieved by any other artist of the frontier scene. In this medium he was decidedly a more successful painter than Eastman, but, though he recorded accurately what he shared in, it was a white man's world and white men's adventures that he set down on paper and later on canvas. The Indians merely provided color. Charles Bodmer in Eastman's day was known only by the engravings after his paintings published in the atlas accompanying Prince Maximilian's "Travels in North America." He was respected and admired for his able pictorial report on the tribes of the Upper Missouri, but it is only since the showing by the Smithsonian Traveling Exhibition in 1954 of his original watercolors and sketches made on that excursion in 1833-34 that we have been able to assess him properly.

When we look, then, at the painters of the Indian before the Civil War, we put Deas and Catlin and Miller on one side as painters showing an enthusiastic response to the romance of wild life. Bodmer and Eastman, on the other hand, were interested in the red man for his own sake. Their careful study and objective handling of his culture had less dash but greater authenticity. As documenters of Indian life they have no superiors; as painters they excel most of those who undertook the same subjects.

In this work Eastman had the great advantage of leisure and long study. Where Catlin spent months, Miller a summer season, and

Bodmer 1 year, Eastman had 7 years of residence among the Indians. He had no reason for hasty completing of impressions; he had ample time for coming to know the ways of his subjects as well as a white man could. "It is not probable [I turn back to the Missouri Republican of September 16, 1848] that there is an artist in the land so entirely familiar as is this gentleman, by long and familiar intercourse and acquaintance with savage life, scenes, and the natural scenery of the wilds of the Western Valley."

Eastman was first of all a painter, not an ethnographer, but by chance he was drawn into a subject matter in which he became expert. His first works, we have seen, were in landscape, and had he remained on duty in the Eastern States he would no doubt have continued to work as a minor member of the Hudson River School. But the chance that sent him to a far-distant frontier post and put him in daily contact with the Sioux led him to study the Indian and his landscape and he turned his talents and his leisure to Indian genre subjects and the backgrounds in nature against which they must be set. For half a dozen years he painted and sketched without any attempt to exhibit or dispose of his works—he was happily able to paint not for a living but for the sake of painting as he wished. We are fortunate that this was so.

The most notable qualities of his work are naturalness and fidelity. What the friendly Missouri Republican said of one picture can be said of all: "There is no attitudinizing—no position of figures in such a group that you can swear the artist's hands, and not their own free will, put them there." His pictures are "homely truth." They present the commonplaces of Indian life. No drama, no sentimentality, no straining after emotion, no romanticizing. He does not wish to amuse or to excite but to observe, to inform, to interest. Seldom can a painter so free himself from his own personal point of view as Eastman does to become the objective and impartial observer. He does not condemn, he does not approve, he does not patronize. He does not present the Indian as low, crude, and contemptible or as noble, abused, and pitiful. He does not show him as villain or as hero. He merely sees him as a man with customs of his own. Consequently, Seth Eastman has left us a record in paint and pencil that is vivid, fascinating, and reliable.

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